DIVERGENT SELECTION FOR FEATHER GROWTH IN BROILER CHICKENS

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Preface

An experiment on the two lines of grand parent meat-type chickens having fast, k, and slow, K, feathering genes was started in 1982 in the Poultry Husbandry Department at the West of Scotland Agricultural College, Auchincruive. The aim was to study the effect of divergent selection for accelerated and decelerated feathering, within each line, on the productive traits of the broilers' progeny of the different created lines. However, in October 1984, I joined the research team and worked on two batches of the broiler progeny and the third generation of the different lines. After six months due to low number of birds in some lines especially in the control line, we decided to restart with a fresh population which had only the slow feathering gene K.

For analysis of data after consultation with my supervisor, we decided to write to Professor W. R. Harvey, Ohio State University, U.S.A. to obtain the latest version of his computer programme called "Least-squares analysis of data with unequal subclass numbers". In April 1987, the programme was installed and then I was able to analyse my data.

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Finally, thanks to my dear parents and my dear wife, Badri, whose encouragement and co-operation enable me to come through the course happily. Particular thanks to my sons, Hamid and Vahid, for carrying a large part of the burden.

SUMMARY

The objectives of this study were to estimate the genetic parameters of feathering and the response of the unselected trait, body weight, as a result of selection for feathering; also the correlated response of broiler production traits to selection for feather growth in the broiler progeny of different lines; and the response of the broiler progeny of the different lines under normal and high temperatures.

The foundation stock consisting of 600 male and 600 female day-old grand parent chickens was selected from a population of thousands and supplied to the Poultry Husbandry Department by a hatchery of Ross Breeders Ltd., Scotland. Three groups of birds, including males and females, were selected for feathering on the basis of phenotype, insofar as 24/25 days of age feather pattern was concerned, as follows: Fast feathering, Slow feathering, and, a Control group, which was randomly selected.

A grand total of 4023 pedigreed and 3042 broilers progeny from two generations were involved in the statistical analysis of this study.

After two generations of selection, on average, males and females of the fast feathering line gained

+.86 and +.65 units of back score; +4.2 and +7.25 mm of tail length; and +18.4 and +10.0 g of body weight while the males and females of slow group lost -.42 and -.43 units of back score; -2.2 and -3.9 mm of tail length; and -13.7 and -10.2 g of body weight, respectively, compared with the control group.

On the basis of full-sib analysis, heritability of back score in the first generation was found to be .562±.072 and .458±.057 in the second generation. On the same basis, heritability of tail length was .599±.074 in the first and 0.568±.062 in the second generations while the heritability of .839±.078 and .713±.086 was found for body weight around 24 days of age in the first and second generations, respectively.

There was a strong genetic correlation (.733±.053) between tail length and back score, showing they can be a good substitution for each other. Also, there was a high genetic correlation between tail length and body weight (.605±.068). Considering this estimate, phenotypic selection for tail length might be worth considering in promoting a genetic improvement in feathering in the population of chickens carrying the K gene.

The broilers produced from the first generation showed no signs of a significant difference between the

selected lines as regards body weight and feed conversion. But there was a difference between males and females. Males tend to be heavier while females stored a higher percentage of abdominal-fat.

However, when broiler progeny were reared under different temperatures still there was not any significant difference between lines but high temperature (30^{o}C) had a negative effect on growth rate and on feed conversion (except in feed conversion up to 24 days of age).

INTRODUCTION

Producers of commercial broiler breeding stocks frequently employ the sex-linked genes for rate of feathering to produce chicks that can be sexed by the relative length of the primaries and associated coverts wing feathers at day-old. The sex-linked, dominant gene, K, in the homozygous, heterozygous, or hemizygous genotype produces a slow feathering phenotype while the allele k in the homozygous or hemizygous form produces rapid feathering chicks (Hutt, 1949). This means that to produce feather sexable commercial chicks, one must have a line of slow feathering stock. Recent investigations into the relationship of these genes to bird performance and mortality in laying stocks have shown a detrimental effect associated with the K gene (Lowe and Garwood, 1981; Harris et al., 1984; Bacon et al., 1985). Warren and Payne (1945) and Saeki and Katsuragi (1961) reported heavier weight in 12-week-old, rapid feathering New Hampshires. Goodman and Muir (1965) showed that broilers which carried the rapid-feathering gene were significantly heavier (49 g) than those which carried the slow feathering gene.

Also, another major goal in a modern breeding programme is to improve the feed conversion efficiency of the chicken. It seems that one of the components of

feed efficiency could be feather cover, acting presumably as insulation. It is suggested that if feather growth rate could be accelerated, feed efficiency may be improved and a shorter brooding period may be possible. However, according to Douglas (1973) poor-feathering could lead to lowered processing plant efficiency by 20 percent. Also, poorly-feathered broilers are likely to suffer more down-grading from skin damage and this may result in a 9 to 10 percent reduction in selling price (Douglas, 1973). Rapid feathering birds are more uniform for body weight than slow feathering ones (Goodman and Muir, 1965). From the point of view of welfare, a poorly-feathered bird is a potential victim for feather pecking or cannibalism.

Moreover, as more and more birds are killed for the fresh market the procedure of feather removal becomes a more delicate operation. Water temperature in the scald bath operates at a level so that the bloom on the skin is not lost. But in trying to keep the bloom the temperature in the scald tank is not optimum for total feather removal. In the fresh killing line, operators are always required to remove small feathers by hand to complete the plucking process. It would be desirable to have the least amount of pin feathers remaining at killing age and therefore a programme to increase feather growth should improve some of the problems confronted on the processing line. Birds which

feather sooner should have less skin damage from scratches and blister resulting from lying for long periods on inadequately dry litter.

The advantages to be gained from an improved feather growth have not been properly quantified, and these may prove to be only of minor significance.

However, in today's efficient, competitive and changing broiler industry, small differences in chick performance (for example 1% in body weight or 1% in feed efficiency) are important when applied to current production costs and profit margins.

The genetic improvement of any economical trait can be best achieved by selection. The amount of improvement secured by selection depends on the effective use of genetic variation in the population. When two or more traits are involved in the breeding programme, knowledge of genetic and environmental correlations among the traits is necessary to predict the response to selection of traits not directly selected. Heritability , which is the fraction of the total variance attributable to the average effects of additive gene action, is the key factor for any given population to improve the desired traits.

The primary objectives of the present study were:

1. to estimate the heritabilities and genetic correlations involving feathering and body weight,

2. to determine the simultaneous responses of the unselected trait, body weight, as a result of selection for feathering, and

3. to investigate the effect of divergent selection for feather growth on the productive performance of the broiler progeny.

CHAPTER ONE: REVIEW OF LITERATURE

1.1 Genetics and mode of Inheritance

There are several opinions for explaining the genetics and the mode of inheritance of feathering in chickens and several researchers have reported that feathering could be improved by genetic selection plans.

According to the literature, Rogers (1909) was the first who reported about the inheritance of feathering in chicks; he made a cross between White Leghorns and Barred Plymouth Rocks and claimed that the off-spring were all feathered like their father, regardless of the direction of the cross. Serebrosky (1922) reported on a cross between Barred Plymouth Rocks and Russian Orloffs from which he found evidence for a sex-linked gene, K, affecting the rate of feathering. Warren (1925) who crossed White Leghorn and Jersey Black Giant reported on the mode of inheritance of a simple sex-linked recessive gene, k, for rapid feathering. He explained that the character showed clean-cut segregation early in life and the expression of the character was not affected by the vigour of individuals. He also demonstrated that the character could not be recognised in the adult chicks. Kinugawa (1927) reported the existence of a sex-linked

recessive gene for rapid chick feathering in Leghorns and some other breeds; he proved that the character could be inherited through a high fecundity breed as well as by mating of egg type to meat type birds.

Saharova (1926) classified Asiatic breeds as slow feathering types, whereas Mediterranean breeds were rapid feathering.

Danforth (1929) crossed White Leghorn, Barred Plymouth Rocks and Rhode Island Reds and grafted skin from one breed to another. He concluded that two factors could produce slow feathering birds; the first factor was sex-linked which occurs in Rhode Island Reds and the second factor produces an inhibitory effect through the soma. Both of these factors were found to occur in Barred Plymouth Rocks.

Warren (1933) reported a simple autosomal recessive gene, retarded (t), which modifies the expression of the ordinary early feathering in White Leghorn chicks. At day-old, the normal number of well developed secondary flight feathers was reduced to the first three secondaries. In ten day old chicks, it prevented the development of the tail as well as the above mentioned secondary flight feathers. The retarded gene cannot be identified in the adult birds. He also concluded that the presence of the sex-linked late feathering gene interferes with the identification of

the retarded factor.

Lloyd (1939) made a study of feathering in Barred Plymouth Rocks, Rhode Island Reds, Cambras and White Leghorns. He observed varying degrees of feathering at 4, 6 and 8 weeks of age and he showed that it is possible to produce uniform rapid feathering in Rhode Island Reds and Barred Plymouth Rocks. He concluded that the rapid feathering gene is dominant in the mode of inheritance within the breeds mentioned.

Radi and Warren (1938) reported that selection in Rhode Island Reds to produce strains which were genetically different in degree of feathering at seven weeks of age was effective. They concluded that superior feathering was incompletely dominant to poor feathering, but did not determine the number of genes involved. They also concluded that the genetic differences which were established could be probably due to modifying factors acting upon the sex-linked dominant late feathering gene for which the birds were known to be homozygous.

Darrow (1941) studied the relationship of feathering at day-old and at broiler age; he showed that feathering at broiler age could be detected at day-old by counting the number of well developed secondaries in chicks homozygous for the sex-linked early feathering genes.

Hays and Sanborn (1942) pointed out a single dominant autosomal gene, X, which has a cumulative effect and must be supplemented by recessive gene sl to give complete rapid back feathering in the Rhode Island Red breed. They showed the gene sl can be recognised by the presence of tail feathers at ten to twelve days of age, and concluded that only those birds which are genotypically sl- and XX will be fully back feathered at 8 weeks of age.

Darrow and Warren (1944) observed variation in the degree of feathering at different ages in chicks homozygous for the sex-linked early feathering gene. They reported that the most variable characteristics were the number of secondaries at hatching day followed by development of tail at ten days and back feathering at six and eight weeks of age. The number of well developed secondaries was positively correlated with the degree of back feathering at eight weeks (r= 0.469 for females and r= 0.381 for males). Tail length at ten days of age was the best predictor of back feathering at six weeks of age. The correlation between these traits was 0.517 for males and 0.527 for females which was highly significant (P>.01).

They also provided evidence that an autosomal recessive modifying factor, "modified early", suppressed feathering in homozygous sex-linked early feathering chicks. They concluded that it could be the same factor

which was previously reported as a "retarded". They also claimed an autosomal dominant factor "intermediate" which may improve feathering in late feathering chicks.

Jones and Hutt (1946) demonstrated that in White Leghorns, a mutant gene, t^s, was a new allele of the tardy alleles series which prevents the appearance of the sex-linked rapid feathering trait. The gene was responsible for slow development of tail feather growth as well as of secondary feathers of the wings and of contour feathers over the body up to eight weeks of age. The same conclusion was reported by McGibbon and Halpin (1946) in the Rhode Island Red breed of chicks.

Mueller and Moultrie (1952) claimed 100% accuracy in the classification of early and late feathering chicks at ten weeks of age, when body weight gain could also be assessed. At this age early feathering chicks had moulted the number 2 secondary wing feathers and had long tails, but late feathering chicks had not moulted the number 2 secondary and had heart-shaped tails.

Hale (1952) who studied the White Wyandotte breed showed that chick feathering in the first few weeks was largely controlled by the sex-linked allelic series in which a recessive gene leads to rapid feathering. He concluded that the rapid feathering gene prevented the action of other genes leading to poor feathering at around two months of age.

Hurry and Nordskog (1953) showed that only a small part of the variation in broiler feathering is attributed to the sex-linked gene k and variation within the fast feathering group was as great as in the sex-linked slow feathering one. From these results, they claimed that the concept of heritability is applicable to feathering as to any other trait showing continuous variation. So, they concluded that broiler feathering may be considerably improved upon even after the k gene is made homozygous.

Plumart and Mueller (1954) reported sex-linked early feathering pullets possessed better back feathering at 6, 8 and 10 weeks than late feathering pullets but the difference was not detectable at 12 weeks of age. Early feathering cockerels had better back feathering at all four ages and possessed few pin-feathers at twelve weeks of age. They concluded that a visual classification of feathering at 6 weeks was a good guide to the degree of maturing of plumage up to 12 weeks.

Krogseth and Ukkelberg (1955) reported slow feathering can be detected at day-old if the length of secondary number two is less than 6 mm. They also concluded that slow feathering may depend on a sex-linked gene in some cases, and on an autosomal in others.

Pilla (1958) described criteria for assessment of feathering, as early or late at 1, 10, 30 and 60 days of age. He crossed New Hampshire males and Barred Plymouth Rock females and confirmed that the gene for early feathering is a simple recessive and sex-linked; but from the results he concluded that it is also possible that there was a sex-linked gene which inhibits the expression of the dominant allele for rate of feathering in homozygous males.

Siegel et al. (1957a) studied the phenotypic characteristics of homozygous (KK), heterozygous (Kk) and hemizygous (K-) genotypes in a late feathering Rhode Island Red line. They reported that the sex-linked gene for late feathering was incompletely dominant to the early feathering allele and they showed a dosage effect, at least during the first three weeks of life. Significant variations were observed between KK males and K- females and between KK males and Kk males as well. The KK males were much poorer feathered than K- females or Kk male chicks. They claimed that by adoption of a standard of 6 mm length of the number 2 secondary as the minimum length at hatching, 99% of KK males and 64% of Kk males would be culled. He concluded that the length of number 2 secondary at hatching and back score at three weeks seemed the best for classification of the birds for feather growth.

Siegel et al. (1957b) reported most of the genetic variation for the feathering traits were due to additive genes and the best progress in selection would be made in mass selection with sex-linked early feathering birds. They rejected a dosage effect of the sex-linked gene because of better feathering of hemizygous female (k-) than homozygous male (kk). Heritability estimates of some feathering characters were moderate (0.25 - 0.40) to high (> 0.40).

Lohle and Mulsow (1967) examined the feathers of 750 male and female chicks from White Leghorn, Light Sussex, New Hampshire, White Rock and White Cornish breeds at day old, two and four weeks of age and demonstrated that at day-old future ability of chick feathering can be predicted from the number and development of the primary and secondary feathers. They stated that in the breeds studied, a single evaluation of feathering ten hours after completion of a hatch is sufficient, even although 21 hours have elapsed from the emergence of the earliest chicks to the latest.

Somes (1969) studied the mode of inheritance of a new mutant allele at K locus of the sex chromosome of the chicken. He crossed males homozygous and female hemizygous for the new allele, K^n, a sex-linked delayed feathering gene and showed that it was dominant to the K and k alleles and greatly retarded feather development

as well as comb size. In some cases the female progeny remained near naked well into adult life. He showed that in affected juveniles, the down feathers were not pushed out by developing juvenile feathers; in time, they begin to wear and break off, and the birds are left naked from 5-6 weeks of age until late in juvenile life. Males heterozygous for K^n are never as completely naked as male homozygous or female hemizygous, but the rectrices rarely develop (a summary of feather structures is explained in Appendix I). Similar studies by McGibbon (1977) were conducted on slow feathering birds. He deduced that slow feathering is due to a new mutant gene ,K^s, at the K locus on the sex-chromosome. He showed it was dominant to both late (K) and early (k) feathering and the birds would be naked up to 12 weeks of age. When in adult, they appear like normal feathered birds. He concluded K^n was probably dominant to K^s.

Overall, from the above reports, it can be concluded that two series of alleles, k and t, influence the feathering of the chickens. On the one hand, the k series is sex-linked and consists of k, K, K^s and K^n alleles which express different rates of feathering ranging from rapid to extremely slow feathering. Each allele is dominant on the others in favour of extremely slow feathering. So, the k allele is the most recessive one in the series. On the other hand, the t series are autosomal genes and consist of T, t^s and t which are

called normal, retarded and tardy genes. Each allele is dominant on the others in favour of normal. So, the T allele is the most dominant one in the series.

1.2 Feathering and Growth (Production)

Two important characteristics of meat-type chickens are feathering and growth rate. These characteristics are important due to their strong influence on economical returns in poultry meat production.

Several researchers have reported that growth rate and other performance criteria are associated with the degree of feathering. Gericke and Platt (1932) in work with Barred Plymouth Rocks secured a coefficient of correlation of 0.80 between body weight and feather development when the chicks were 8 weeks old. It should be noted that these birds were raised on different protein levels.

Jaap and Morris (1937) studied the variation in body weight and rate of feathering at 8 weeks of age in six general purpose breeds and crosses. The data indicated that there was positive correlation ($r = 0.23$) between rate of growth and rate of feathering. They showed that reciprocal crosses between rapid and slow

feathering stocks gave a more or less intermediate feather development.

Hays and Sanborn (1942) had some evidence which indicated a lower mortality rate in the male of rapid feathering groups than slow feathering ones up to the age of 5 months.

Warren and Payne (1945) using New Hampshire chicks found that at twelve weeks of age, those chicks having the sex-linked rapid feathering gene were heavier than those lacking the gene. They concluded that it might be as a result of genetic or physiological linkage between early feathering and rapid growth, or, alternatively it might be that possession of a well covered body at an early age favours growth rate.

Glazener and Jull (1946) concluded that there is a relationship between the number of secondary feathers at hatching and body weight at broiler age. Those individuals having six or more secondaries were heavier than those with fewer secondaries.

Hays (1951) reported that in a Rhode Island Red population, the sex-linked gene (k) had no effect on body weight at eight or twelve weeks of age, but the autosomal gene (X) was associated with rapid growth. He concluded that to achieve superior growth in a broiler strain it was necessary to make selections for complete back feathering at eight weeks of age.

Plumart and Muellar (1952) compared the effect of sex-linked early and late feathering on the growth of chicks up to 12 weeks of age. They reported that it was only in the female that a significant increase in weight was obtained in early feathering strains. The early feathering birds had a lower percentage of pin feathers and, so, a better carcass appearance.

Hurry and Nordskog (1953) from the data obtained on Barred Plymouth Rock and New Hampshire breeds, reported that the heritability of feathering was estimated at between 0.33 and 0.42 at eight weeks of age, and, at the same age, heritability of body weight was estimated at about 0.33. Also these two traits showed a fairly high phenotypic correlation as well as a positive genetic correlation, so they concluded that genes influencing feathering also influence growth rate.

Saeki and Katsuragi (1961) studied the effect of early and late feathering genes on the weight of newly hatched chicks and the post hatching growth rate in New Hampshire and White Leghorn breeds and their reciprocal crosses. A significantly heavier weight at hatching, and at two, five and ten weeks of age were found in early feathering groups of New Hampshire than in late feathering ones. Also there appeared highly significant differences between the two feathering types among progeny produced by crossing heterozygous New Hampshire

males and hemizygous White Leghorn females. From these results, they concluded that the sex-linked alleles k and K which controlled feathering in the New Hampshire seemed to have pleiotropic action to the growth of chicks.

Sheridan and McDonald (1963) reported that birds carrying the K allele were larger at 5 weeks of age, whereas those carrying the k allele were larger at 10 weeks of age. Goodman and Muir (1965) analysed data on the body weight of slow and rapid feathering chicks and found rapid feathering birds were significantly heavier (+0.11 pounds) than slow feathering ones.

Lohle and Mulsow (1967) studying White Cornish and White Rock breeds showed that there was a highly significant regression of total feathering on four week body weight. They assumed, therefore, that selection for high four week body weight within a population would have a positive influence on the degree of feathering at this age. They also noted that the length of the primary feather number 4 at two and four weeks of age was a suitable criterion for feather evaluation as it significantly correlated with feather development on the entire body and could be easily measured.

According to Merat (1967), who studied different loci of genes, feathering before hatching, growth rate and sexual maturity were linked to the alleles K and k.

On the contrary, some other researchers reported a relatively weak correlation between feathering and growth rate. For example, Darrow and Koonz (1948), comparing rapid and slow feathering chicks within nine strains of White Plymouth Rock, found no difference in growth rate to eight weeks of age. Also, Godfrey and Farnsworth (1952), making a comparison within families in three breeds, also concluded that rapid feathering gave no advantage in growth to ten weeks. They found a higher mortality among the rapid feathering chicks but did not consider this difference to be significant.

Furthermore, Hale (1952) showed by statistical analysis of the body weight of a White Wyandotte line at eight weeks of age that rapid feathering was not connected, to any significant degree, with more rapid growth. He also observed feather picking rarely occurred amongst rapid feathering chicks.

Likewise, Lowe et al. (1965) reported that heavier one day-old chicks were obtained from rapid feathering hens but no difference in rate of growth was associated with the two alleles K and k. Yoshida and Saito (1985) confirmed that the rapid feathering gene had no detectable effect on survival rate or adult body weight.

Overall, it seems that there are different results from the experiments for the correlation of feathering

and body weight gain ranging from high positive correlation (Gericke and Platt, 1932) to lack of any correlation (Hale, 1952)

1.3 Feathering and Reproductive Traits

According to Martin (1929) the degree of back feathering in Barred Plymouth Rocks was closely related to the body weight gain and rate of egg production. Heavier chicks and better egg production were obtained from early feathering hens. But no linkage was found between genes for rate of back feathering and sex-linked gene E or autosomal gene E′ for sexual maturity. Hays and Sanborn (1942) reported that there was no relationship between sex-linked genes (sl) for rapid feathering and sexual maturity, egg production and egg weight as well as the other inherited characters affecting egg production. Lowe et al. (1965) reported that heavier eggs and earlier sexual maturity were obtained from rapid feathering hens.

Krogseth and Ukkelberg (1955) reported that slow feathering birds grew slowly and tended to have a delayed sexual maturity. Fast feathering females came into lay 13 days earlier. Somes (1970) did a series of studies on the effects of a new allele at the K locus, K^n, on various quantitative traits by mating a mutant

(K^n)and normal (k) White Leghorn chickens. He reported that in addition to the late feathering and smaller comb, those possessing the K^n gene showed significantly reduced body weight and less total egg production than normal birds. Also, the stock possessing the mutant, K^n, had a lower metabolic rate, poorer hatchability, poorer livability, smaller eggs, more misshapen eggs, and later sexual maturity than birds with the k gene. Yoshida and Saito (1985) reported that the rapid feathering gene had no detectable effect on survival rate, egg weight or rate of egg production, but fast feathering pullets reached sexual maturity significantly earlier, by an average of 8.2 days, than slow feathering pullets.

Recently, Dun and Macleod (1986) reported on a comparison between a vent-sexed strain and a feather-sexed strain of layers. They stated that there were no differences between the levels of egg output, body weight or feather score, during the 52 weeks laying cycle.

1.4 Feathering and Nutrition

It is already clear that a covering of the bird's body by feathers would protect it against skin damage as well as the regulation of body temperature. As reported by Jull (1938) feathers make up about 7% of live body

weight and account for 4 to 9% of the empty live weight, depending upon the sex and age of the bird (Card and Nesheim 1972). The composition of the feather shows it contains various amino acids, vitamins and minerals, and the nutritional adequacy of the diet appears to be the major factor influencing both the structure and growth of feathers in chickens (Wyatt et al. 1975).

Gericke and Platt (1932) investigated the effect of varying amounts of protein in the ration on feather growth in Barred Plymouth Rock chicks from hatching to 8 weeks of age. Their data indicated that a higher level of protein increased the rate of feather growth.

Anderson and Warnick (1967) reported that by reducing the levels of some essential amino acids such as leucine, arginine, valine, isoleucine, tryptophan, or phenylalanine and tyrosine, growth rate was reduced from 11 to 4.5 g per day; in addition, abnormal feather structures were observed. Abnormalities included curled feathers, spoonshape feathers, and feathers with a ragged and thin appearance. Another characteristic of amino acid deficiencies was the abnormal curling of feathers away from the body (Robel, 1977). However, the feather abnormalities were somewhat similar, but these symptoms developed to different degrees according to the individual amino acid and the severity of deficiency (Anderson and Warnick, 1967). It is worth noting that some of these feather abnormalities are also

characteristic of a range of vitamin deficiencies (Summers et al., 1978).

Schaible (1970) showed that chicks and pullets deflect large proportions of their sulphur amino acid intake to the growth of feathers which contain 10% cystine. He also reported that a fast feathering Leghorn breed showed a better feathering response to the supplementation of arginine and glycine, compared to the slow feathering Plymouth Rock breed which showed less response. It was suggested that arginine and glycine are factors affecting the feathering rate of young birds. However, Waterhouse and Scott (1962) showed that hemizygous fast feathering female chicks (k) did not require a higher concentration of dietary glycine than homozygous slow feathering males (KK). Wheeler and Latshaw (1981) confirmed the critical role of dietary amino acid in feather growth and reported that the major amino acids involved in the synthesis of feather keratin are the sulphur containing amino acids, cystine and methionine. Champe and Maurice (1984) confirmed that cystine is the major component of keratin but they reported that the importance of methionine in the process is due to its conversion to cystine. Morgan (1984) stated, that this conversion occurs in both the feather follicle and in the liver.

Donaldson et al. (1955) studied broiler type

chickens. They gave the chickens rations differing in protein and energy levels, and showed that as the energy level of diet increased from 35.7 to 48.6 calories of productive energy per pound for each percent crude protein, poor feather condition at market age was observed.

Recently, Wheeler and Latshaw (1981) conducted an experiment to determine the broiler's total sulphur amino acid requirements and the replacement value of cystine for methionine. They reported that maximum feed efficiency was obtained with cystine representing 54% of total sulphur amino acids during the period of rapid feather development. Once feather development was complete, the value of cystine declined in feather-sexable broilers. So, they concluded that there is a potential to have different feeding programmes for male and female broilers depending on the rate of feathering.

It seems vitamins and minerals also have a significant role in feather growth. Daghir and Balloun (1963) and Gehle and Balloun (1965) reported that chicks which received a vitamin B6 deficient diet showed a degenerative change in the wing feathers which was cured by pyridoxine supplementation. Toth et al. (1964) reported that chickens fed the vitamin D3-deficient diet developed a wing feathering disorder. From the second and the third week of life, rachitic signs developed and vane growth was retarded. While the

vexillum at the distal end of the wing feathers was normal, at the proximal end a shorter or longer portion of the rachis, remained bald. Supplee (1966) observed a characteristic feather abnormality followed by bleeding of the feather pulp when chicks were fed a ration deficient in selenium and vitamin E. A similar condition was reported by Taylor (1967) when the chicks were fed a diet deficient in pantothenic acid, folic acid, biotin or nicotinic acid.

Sunde (1972) upon making a comparison between a ration of practical type containing 38 to 44 ppm zinc, and a ration containing a higher level of zinc (75 ppm or more) in pullet chickens, concluded that feeding the higher levels of zinc for only the first week of life gave excellent protection against fraying of feathers.

Baker and Molitoris (1975) conducted an experiment to ascertain if supplementing a completely purified diet with tin, vanadium, chromium and nickel would enhance chick performance between hatching through to 27 days of age. Their results showed no effect on rate and efficiency of gain or on feather development.

It was reported by Charles and Kiker (1974) and Kiker and Sherwood (1974) that anticoccidials could have possible negative effect on feather growth. They suggested that anticoccidials, such as lasalocid and

monensin, induce abnormal feathering by increasing a methionine requirement of the chicken. However, Damron et al. (1977) and Leeson and Summers (1983) after several different experiments failed to show any significant interaction between ionophores and requirements for total sulphur amino acids. Kiker and Sherwood (1974) concluded that it is difficult to have conclusive evidence regarding the effect of anticoccidials, mainly due to various management, nutritional and environmental factors which complicate the antagonism.

1.5 Feathering and Hormones

It has been found that endocrine glands play an important role in the more direct mediation of productive ability. Among them, thyroid studies revealed that thyroid secretion might have an important role in the complex of factors responsible for feather development. Ringer (1965) reported that thyroidectomy in birds results in feather structure alteration with loss of barbules and colour while Voitkevich (1966) reported that after thyroidectomy, feather formation ceases except for the wing feathers which were not thyroxin dependent. Schultze (1930) described thyroid atrophy in Plymouth Rock chicks which were completely naked except for the wing feathers.

Overall Spearman (1971) pointed out that the thyroid hormone had an important role in growth, differentiation and patterning of plumage due to increasing the metabolic activity of the feather-forming cells. He also concluded that the down feathers of the young chick develop without hormonal influence, but most feathers in juveniles and adults are dependent on levels of thyroxin. Schultze and Turner (1945) reported upon a comparison of the average thyroid secretion rate: fast feathering White Leghorn males had a higher rate than slow feathering White Plymouth Rock males on a body weight basis.

Cole and Reid (1924) observed, in an adult stock, that birds which received desiccated thyroid in their ration showed more rapid feather replacement than others. Radi and Warren (1938) presented data on chick feathering for the Rhode Island Red breed. They reported that thyroxin injection definitely stimulated feather development. Parker (1943) reported that slow feathering Rhode Island Red chicks receiving a minimal dosage of thyro-protein in their ration showed improved growth rate. A higher dosage of thyro-protein caused a highly significant increase in the rate of feathering. Irwin et al. (1943) noted a slight increase in growth rate and feathering of White Plymouth Rock chicks receiving 36 g of thyro-protein per 100 lb. of mash. They also concluded that the rate of feathering tended to increase

in direct proportion to the amount of thyro-protein added to the ration. In further studies Turner et al. (1944) also had some positive response in rate of feathering from feeding thyro-protein at a rate of 45 g per 100 lb. of feed to Barred Plymouth Rock cockerels. Wheeler et al. (1948) reported that male chicks fed 0.02% thyro-protein in a feed to 12 weeks of age feathered early compared to the control group. Boone et al. (1950) indicated that an average of 23 g of thyro-protein per 100 lb. of feed significantly increased the feathering rate of slow feathering Rhode Island Red chicks.

Somes (1975) studied the effect of testosterone propionate at the rate of 3 mg/100 g body weight, on comb size, uropygial gland and other traits of extremely slow feathering, K^n, chicks. Birds of both sexes of five genotypes kk, K^nk, K^nK^n, K-, and K^n- were sacrificed to measure the internal organs as a percentage of body weight. The results showed that K^n birds had significant hypertrophy of the uropygial gland and reduced comb size. The heart and adrenal gland were significantly larger in birds which carried the K^n allele than in those that lacked the allele. Testosterone treated chicks of KK^n and K^n- genetic make up were both smaller in comb size and exhibited delayed feathering than the testosterone treated KK and K- chicks.

1.6 Sex Effect in Feathering

Many investigators have reported the relationship between sex and feathering. Serebrosky (1922) from a cross of Russian Orloff males with Plymouth Rock females noted that in progeny all cockerels showed slow feather development while all pullets showed rapid feather development. Later, Warren (1925) obtained the same results in his first generation of crossing White Leghorn males to Jersey Black Giant females. In further investigations, he made a reciprocal cross between birds in the first generation. The results showed that both male and female offspring were slow feathering birds. So, he concluded that rapid feathering is controlled by a recessive sex-linked gene and the dominant allelomorph caused slower feather development. Martin (1929) confirmed the dimorphic feather difference in Barred Plymouth Rock chicks; the female feathering was more rapid.

Saharova (1926) called attention to sex differences in the rate of feathering of the general purpose breeds, to the slow feathering in the Asiatic breeds, and fast feathering in Mediterranean breeds.

Jaap and Morris (1937) in an experiment with different breeds of chicken reported that at eight weeks

of age 20% of the variation in feathering is due to sex.

Radi and Warren (1938) studied a strain of homozygous late feathering Rhode Island Red chicks. Through selection procedures, they established two strains, one called well-feathered and one called poor-feathered. As a result, they concluded that the time of appearance of feathers seems to be closely related to sexual phenomena up to the broiler age. This characteristic was entirely eliminated at maturity. Hays and Sanborn (1942) in a similar experiment with fast feathering Rhode Island Red chicks reported that tail feathers of females started to appear three days earlier than those of males. They claimed that under continuous selection for rapid feathering, this sexual dimorphism almost completely disappeared.

According to Hays (1951) the degree of back feathering in Rhode Island Red chicks is due to the action of sex-linked gene sl(k) as well as supplementary autosomal gene X. He presumed that the degree of back feathering in females is more dependent on the autosomal gene X, because females can never carry more than one dose of sex-linked gene sl. In a further investigation on sexual dimorphism, Hays (1952) studied a Rhode Island Red line and Leghorn Red hybrids. Both groups carried gene sl for fast feathering. He found that Leghorn hybrid females had a tail length of 2.08 ± 0.09 cm and

males a mean of 1.87±0.04 cm at ten days of age. In a Rhode Island Red stock, at the same age, females had average tail length of 1.92±0.02 cm while males averaged 1.60±0.05 cm. The difference between the sexes in both groups was significant. He concluded that sex dimorphism in tail length occurs at early ages in favour of the females. However, if the recessive gene sl has an effect on tail length, males might be expected to develop longer tails since they carried two doses of this gene. Since it was females who showed greater tail length than males, it was described as being due to the endocrine system of the females. In contrast, Hurry and Nordskog (1953) demonstrated conclusively that the larger tail in the female in early life was completely due to the action of sex-linked gene, k.

Siegel et al. (1957a) studied sexual dimorphism for six feathering traits in early feathering White Plymouth Rocks. Overall, he found that females were significantly superior to males on the basis of back scores at 10 days of age. Also, breast feathering scores of females received significantly higher scores than the males in three generations. With regard to the back area covered with feathers at five and seven weeks of age, the males had poorer feather condition than the females. Washburn and Siegel (1963) studied sexual dimorphism in White Rock chicks. They indicated that feather development of the back pterylae, was in evidence at

four weeks of age, with the females being better feathered than males.

McDougald and Keshavarz (1984) studied the rate of feather growth in genetically slow feathering Hubbard broilers. It was found that feathers on male chicks were shorter at ten days of age but grow faster than those on female chicks. So, at thirty-one days of age, male chicks had longer feathers than female ones. They also reported that there was no significant difference in back score at fifty-two days of age.

Morgan (1981) and Engler et al. (1985) showed that the amino acid, particularly cystine, requirements of the female broilers in a starting ration at an early age were slightly higher than males. So, they concluded that the higher requirement was due to the differences between sex in the rate of feathering. In the finishing ration, cystine had no effect on feed conversion or growth but had a positive effect on feather yield. So, Morgan (1981) concluded that cystine requirements reflect the differences in feather growth rate between males and females.

Overall, it can be pointed out that sexual dimorphism is mainly due to the sex-linked gene, k, and partially due to the functioning of the endocrine system. However, there is general agreement that females feather more rapidly than males.

Finally, it should be noted that sex dimorphism for growth and body weight has been well known for a long time in poultry. Siegel (1962) from a selection experiment for body weight at eight weeks of age had demonstrated that female chickens were 12.5% lighter than the males. Also, Washburn and Siegel (1963) showed that at 20 days of age the male chickens started to have significantly higher body weight compared to females.

1.7 Feathering and Temperature

Chickens are homoiothermic that is, regardless of changes in environmental temperature, their physiological system adjusts to maintain a near constant body temperature.

Birds have developed some physical characteristic and some metabolic mechanisms in order to regulate body temperature. Among the physical mechanisms sensible and insensible heat lost are notable. Insensible heat is the indirect heat loss through water evaporation from the body. At normal or low environmental temperatures generally cutaneous and respiratory insensible heat loss are equal, but at high temperatures the respiratory insensible heat loss may rise up to six times that of the cutaneous heat loss (Van Kampen, 1974; Arieli et al. 1890; Chwalibog et al., 1985). Sensible heat loss may be

defined as the direct heat loss from the body to the surrounding environment. The rate of sensible heat loss depends upon several factors, the most important of which is the temperature gradient existing between the bird and the environment (Freeman, 1974). Thus, logically as the ambient temperature approaches that of the bird's deep body temperature, the sensible heat flow decline toward zero. In this regard, the insulatory role of the feathers in the energy balance could be considered. However, it seems, the effect of feathering on heat lost in broilers is a relatively unexplored area. However, some research studies with layers or adult cocks have shown that heat lost from naturally or artificially defeathered birds rises rapidly as temperature falls, compared with fully feathered controls. O'Neill et al. (1971) studied the metabolic costs of poor feathering. Their measurements of the fasting heat production of mature cocks showed that the conductance of artificially defeathered birds was more than two times that of normally feathered birds. Richards (1977) reported a similar increase in the conductance for poorly-feathered hens selected from laying stock. He confirmed these hens lost over twice as much sensible heat as well feathered hens over the air temperature range from zero to 30°C. He also reported the zone of thermoneutrality of the poorly-feathered bird was displaced towards a higher environmental temperature than the well-feathered bird.

Because the chicken is homoiothermic the only recourse it has, when heat losses escalate, is to consume additional feed in order to make up the heat deficit. Emmans and Charles (1977) made a comparison between laying hens, which were selected on the basis of subjective visual score on a scale of 1 (complete, undamaged plumage) to 5 (almost completely naked), and reported that for each unit increase in feather score, maintenance energy requirement increased by 9%. They also presented an equation which was adjusted for body weight, egg weight and metabolizable energy of diet, to determine feed intake in different temperatures. Leeson and Morrison (1978) also indicated that feed efficiency in laying hens was significantly correlated with feather cover. Tullett et al. (1980) reported that artificial removal of the feathers from the neck and breast region (equivalent to 17% of the feathered body area) of laying hens led to a 10% increase in food consumption.

According to Keshavarz and Fuller (1980) there is general agreement among a number of investigators that maximum growth and feed efficiency is not obtained when broiler are grown in environmental temperatures constantly above or below an optimum range for their age.

Dale and Fuller (1980) showed that factors other than feed intake are responsible for the adverse effects

of heat stress. They claimed that only 63% of growth depression due to heat stress is directly related to reduced feed intake.

Hurwitz et al. (1980) suggested that generally the effect of temperature on metabolism is more complex than is often reported, since some of the responses are not linear. For example, maintenance energy requirement decreases with constant temperature above 28°C or under 24°C, while there is a trough between 24-28°C. Also there is curvilinear relationship for amino acid requirement per unit of energy. They concluded that the linear relationship between environmental temperature and feed intake is as a result of non-linear function of weight gain and maintenance energy requirement with temperature.

Hurwitz et al. (1980) when modelling amino acid requirements in relation to environmental temperature, assumed that maintenance energy requirement is the only one to change with temperature and that energy required for production is independent of temperature, and showed the curvilinear effects for the requirements of arginine, leucine and sulphur amino acids. Since energy requirements decrease up to 27°C, there is an increase in requirements per kcal of metabolizable energy up to this point, with the decline in weight gain and an increase in the energy requirement for maintenance above

27°C; there is a concomitant decline in amino acid requirements.

One of the major concerns of the broiler industry at the present time is the carcass fat content, especially in the abdominal area. Mickelberry et al. (1966) reported no significant temperature effect on the ether extract content of various tissues of chicks reared at 21°C and 29°C. These workers did observe a trend, in all tissues except liver, toward a higher ether extract content in the 29°C samples than in the 21°C samples. Cabana et al. (1974) reported that the broilers which were reared under heat stress had higher abdominal fat. Kubena et al. (1972) also indicated a direct relationship between carcass fat content and temperature over the range of 7-32°C, and that this was independent of diet protein level.

Hurwitz et al. (1980) concluded that it is likely that body fat deposition will decline at high temperature because of the increased maintenance energy requirement.

1.8 Feathering and Other Environmental Factors

Among the other environmental factors, light is one of the factors which can influence feathering and performance of broilers. Some experiments have been done by researchers, using different lighting programmes to

achieve the best feathering and production. Moultrie et al. (1954) studied two groups of New Hampshire-White Plymouth Rock crossbreds, reared on different lighting regimes, 10 and 15 hours daily, to six weeks of age. Then both groups were divided into four finishing light regimes, 5, 10, 15 and 24 hours light a day to 12 weeks of age. At the end of the second period, those who had been under continuous lighting were significantly better feathered compared to the other groups. Sammelwitz (1967) upon making a comparison between two groups of commercial type broilers, growing under low level light or natural day light with supplemental night light reported that those kept under low level light were less active and showed poor feather and comb development.

Marr et al. (1971) investigated the effect of different photoperiods on growth, feed efficiency and feathering during a nine week experimental period. The birds for the first four weeks were placed on litter, then in a wire cage. He reported that continuous illumination contributed to poor feathering as well as a decreased growth rate up to 4 weeks of age. There were no apparent differences in feathering at 9 weeks of age.

Other environmental variables possibly affecting feathering are bird density, litter condition, humidity and temperature. Wells (1972) in an experiment with light weight hybrid pullets, at four different stocking

densities (0.070, 0.093, 0.139 and 0.186 m^2 of floor area per bird) showed a significant relationship between poor tail feathering and stock density. Scholtysseh and Gshwindt-Ensinger (1983) investigated the effect of three different densities (24, 32 or 40 kg live weight per m^2) and two different trough lengths (1.9 or 3.2 cm per bird) on broiler chicks. They concluded that densities higher than 30 kg live weight per m^2 had an adverse effect on feathering and feed conversion.

Harris et al. (1980) substantiated that broiler chicks on new litter showed significantly better feathering than those reared on built up litter.

Radi and Warren (1938) in two experiments studied the effects of humidity and temperature on feathering. In the first one, they indicated that those chicks under high relative humidity (70%) had significantly better feathering than those under low relative humidity (50%). The result of their second experiment indicated that low temperature (about 21^oC) had a stimulating influence on feather growth. The percentage of improvement in female birds was 28.5 compared with a higher temperature (about 29^oC).

Finally, it should be noted that feather pecking phenomenon could have a considerable effect on feather length measurement, especially in case of tail feathers length.

1.9 Heritability

It is already known that only the genetically determined variation which can be utilised for a permanent improvement of the production traits in a population. Most of the economical traits in poultry such as growth rate and egg production are influenced by many alleles at different loci (generally called quantitative traits). There are also a number of non-genetic or environmental factors which contribute markedly variation among individuals. In making breeding plans it is therefore necessary to know the relative importance of heritable and non-heritable variations of the traits. However, the total variation for any quantitative traits is due to heredity, o^2H; environment, o^2E; and the interaction between them, o^2EH. The hereditary variance is the sum of the additive effect of genes, the dominance deviation and the interaction deviation, epistasis. Thus, the total variance components which make up the phenotypic variance of a trait can be formulated as:

$$\sigma^2P = \sigma^2A+\sigma^2D+\sigma^2I+\sigma^2E+\sigma^2EH$$

In this regard, Pirchner (1969) defined heritability in a broad sense as "the estimation of that proportion of phenotypic variation caused by differences in the whole genotype" which is composed as follows:

$$h^2B = \frac{\sigma^2A+\sigma^2D+\sigma^2I}{\sigma^2A+\sigma^2D+\sigma^2I+\sigma^2E}$$

In a more precise inheritance manner, the definition of heritability in narrow sense is limited to the differences in additive genes effects or in breeding values relative to the total phenotypic variation:

$$h^2N = \frac{\sigma^2A}{\sigma^2A+\sigma^2D+\sigma^2I+\sigma^2E}$$

In breeding programmes, the heritability values in the narrow sense are the main concern because it estimates that part of genetic effect, additive, which is expected to be recovered in the successive generations.

1.9.1 Methods of Estimating Heritability

There are different methods of estimating heritability which were developed by many researchers. It seems, depending on the experimental design and the trait of interest, each method of estimation has been used. The most common methods of estimating heritability and those which are frequently used in poultry were discussed by Dickerson (1969) and Falconer (1981). Those

methods include the following techniques:

1. Parental half-sib correlation: $4\sigma^2s/\sigma^2P$
2. Maternal half-sib correlation: $4\sigma^2d:s/\sigma^2P$, and
3. Full-sib correlation: $2(\sigma^2s+\sigma^2d:s)/\sigma^2P$

Where:

σ^2s is the estimated sire components of variance,

$\sigma^2d:s$ is the estimated dam within sire components of variance, and

σ^2P is the phenotypic variance.

The merits of each method of estimation are discussed by Falconer (1981). In general, parental half-sib correlation is expected to be less biased than maternal half-sib because of the confounding of maternal effects with the dam component of variance in the analysis of variance procedure. Also, it should be noted that the full-sib method of estimating heritability is intermediate in the amount of bias between the parental and maternal half-sib correlation techniques.

1.10 Phenotypic and Genetic Correlations

In order to express quantitatively the extent to which two variable are related, it is necessary to calculate the correlation coefficient. Steel and Torrie (1980) stated that "correlation is a measure of the

degree to which variables vary together or a measure of the intensity of association".

The unit of correlation coefficient is a dimensionless quantity that may take any value between (-1) and (+1), inclusive. Both of these extremes represent a perfect relationship between the variables, and (0.0) correlation coefficient means the absence of a relationship.

A positive value indicates that individuals obtaining a high score on one variable tend to obtain a high score on the second variable, and those obtaining a low score on the first tend to obtain a low score on the second. On the other hand, a negative correlation shows that as one variable increases, the other decreases.

A correlation arising from the relationship between breeding values for two characters is called a genetic correlation (Falconer, 1981). A degree of relationship arising from correlations of environmental deviations together with non-additive genetic deviation is called an environmental correlation (Falconer, 1981).

The existence of genetic correlations raises the possibility of improving a character that is difficult or expensive to measure, by selecting on a character that is easy and cheap to measure. In the practical breeding, it is called indirect selection.

According to Falconer (1981), pleiotropy (where one gene effects two or more traits) is probably the major cause of genetic correlations, although it is possible for linkage to have a similar transitory effect. Linkage means two or more non-allelic genes are residents of the same chromosome. Some of the linked genes are located closely enough not to be separated by crossing-over during synapsis in meiosis, over a few or several generations. Thus linkage would entail the breeding values of two traits in the same individual to be correlated (Lasley, 1987).

Numerous studies have been carried out to elucidate the practical treatment of genetic correlations and the methods of estimation.

Hazel et al. (1943) stated that in order to estimate a genetic correlation, it is essential to have covariance components between the additive effect of two traits while Lerner (1950) used variance and covariance components in estimating the genetic correlation. Falconer (1981) and Becker (1984) derived the genetic correlation between traits from variance-covariance components of half-sib families in a manner comparable to the methods used for heritability estimates.

The implications of genetic correlation in divergent selection experiments have also been reported.

Siegel (1962) provided formulae to compute the genetic correlation between selected and unselected traits in a nested experimental designs with unequal number of observations. Baker (1984) showed the computational formulae of genetic, phenotypic and environmental correlations from nested unbalanced data. Methods of computing the approximate standard errors of genetic correlation were reported by Robertson (1959), Tallis (1959) and Baker (1984). Harvey (1977) modified the formulae of Tallis (1959) to account for unequal numbers per family. He reported that the loss in accuracy due to adjustments that are made for fixed effects is not considered in the calculation of the standard errors for both heritability and genetic correlation estimates. He also confirmed that these estimates should be considered as minimum estimates of the true standard errors.

The phenotypic correlation between two traits is a function of genetic and environmental correlations. Methods used for estimation are based on the variance and covariance components as reported by Baker (1984).

1.11 Heritability of Feathering

There are a few reports on heritability estimates of feathering. Jaap and Morris (1937) analysed data of feathering scores from six varieties of chickens. They estimated that the total variance for feathering due to

differences in varieties, sires, dams and sex together to be 0.51. The same data were analysed again by Hurry and Nordskog (1953), employing a full-sib correlation technique, in order to make an estimation of heritability within sex and varieties. Feathering rate at eight weeks of age had a heritability estimate of 0.71.

Hurry and Nordskog (1953) reported a genetic analysis of chick feathering where subjective scores were used to determine the degree of feathering at 13 days and at eight weeks of age, based on tail feather length and back feather condition. From the results of a full-sib correlation technique, the heritabilities of feathering in eight-week-old New Hampshire and Barred Plymouth Rock breeds were estimated to be 0.33 and 0.42, respectively. They also reported a positive genetic correlation between body weight and feathering, at eight weeks of age, of 0.24 and 0.78 for Barred Plymouth Rock and New Hampshire, respectively.

In a study Siegel et al. (1957a) estimated heritabilities for the degree of feathering and phenotypic correlation for six feathering characteristics in two groups of White Plymouth Rock chicks which were divergently selected for superior and inferior feathering. Based on intra-sire regression of offspring on dams, heritability values were 0.40, 0.32, 0.49, 0.39, 0.47 and 0.32 for ten-day back score, ten-

day breast score, five-week and seven-week percentage of back area feather covered, ten-week back pin-feather score, and the amount of body down present at ten-weeks, respectively.

Gyles et al. (1959) who divergently selected a population of White Rock breed for susceptibility and resistance to breast blisters, reported that the calculated heritabilities from combined sire and dam components for the breast blister and breast feather condition were .20 and .44 in the blister susceptible line, and zero and 0.01 for the blister resistant line, respectively.

1.12 The Scheme of Utilisation of The K Gene in Broiler Production.

In order to produce feather sexable chickens at day-old a sex-linked gene which affects rate of feathering can be used. Slow feathering gene (K) is dominant to fast feathering gene (k), and if the cross is to be used for sex identification it is necessary to mate rapid-feathering males with slow feathering females. At hatching time the rapid-feathering female chicks from such a cross show well-developed primaries which are longer than the associated wing coverts. In the slow-feathering male chicks, by contrast, the primaries are shorter or about the same length as the coverts. However, in the production of feather-sexable

commercial broiler chicks the following mating (North, 1984) is commonly used:

Parents	Male		Female
	Fast-feathering	X	Slow-feathering
	kk		K-

Offspring	Male	Female
	Slow-feathering	Fast-feathering
	Kk	k-

The grand parents to produce these parents are of the following genotype:

Sire Side				Dam Side			
Line A		Line B		Line C		Line D	
Male	Female	Male	Female	Male	Female	Male	Female
kk	k-	kk	k-	KK	K-	kk	k-

The stock used in the present work were from the line C which provides the sire for the female parent of the commercial broiler.

CHAPTER TWO: MATERIALS AND METHODS

Recently, the idea of developing an early feathering broiler has been initiated at the West of Scotland Agriculture College. Research facilities were provided by the Poultry Husbandry Department at Auchincruive, Ayrshire. In 1982, a commercial breeding company (Ross Breeders Ltd., Scotland) supplied the department with grand-parent day-old chicks carrying the slow feathering sex-linked gene, K, and the fast feathering sex-linked gene, k. It was attempted over three generations to select for slow and fast feathering within each group of birds carrying gene K or k. However, in 1985, it was decided to concentrate on the slow feathering grand-parent broiler carrying K. So, in the same year a new experiment was started with fresh grand-parent day-old broiler chicks from the same commercial company. It was conducted to study some genetic parameters of feathering and the effect of divergent selection on some broiler economical traits.

2.1 Basal Population

A total of 600 male and 600 female day-old grand-parent broilers were supplied to the Poultry Husbandry Department. These had been selected from a population of thousands at the company hatchery.

2.1.1 Management Before Selection

All the birds were wing banded and vaccinated according to schedule (Appendix II) and the male birds were decombed. The chicks were then transported to one of the broiler/rearing houses of the department. The birds were reared in pens on litter in the controlled environment house. Heat was supplied by gas brooders and brooding temperature was 32.5^{o}C decreasing steadily to 21^{o}C at 21 days of age (Appendix III). Thereafter it was attempted to maintain temperature constantly at 21^{o}C until 16 weeks of age.

The lighting programme was 23 hours light and 1 hour dark up to 24 days of age. Then, it was sharply reduced within a week to 8 hours light which was held constant up to 16 weeks of age.

For the first 24 days the birds were given a commercial starter ration called "Gold Start Crumbs" ad libitum. Thereafter, up to 6 weeks of age the birds, separated by sex, were fed the same ration but in restricted form. For the next 14 weeks the birds were fed a pelleted commercial grower ration called "Gold Grow 16 Pellets" (composition of the feeds are presented in Appendix IV while the restricted feeding schedules for each sex are presented in Appendix V).

From 21 days of age, to keep birds silent and to avoid cannibalism, birds were kept in a dim light environment (approximately 2 lux light intensity). Each pen contained at least one automatic bell-shaped drinker to provide water to birds ad libitum.

At 23 days of age for females and 24 days of age for males a total of 30 males and 150 females were randomly selected and classified as the "Control" line. Birds of this line, Control, were randomly selected and bred throughout the course of the experiment for the purpose of comparison. It should be noted that the males of Generations one and two were selected randomly within sires to avoid fertility and hatchability effects on number of the birds produced within sire and to eliminate or at least minimise the possibility of random drift.* From the remaining population, a total of 60 males and 300 females were selected in a divergent selection programme for feathering rate. Mass selection was employed in the selection of two groups of males and females on the basis of feather growth.

2.1.2 Selection Procedures

In most feathering studies, subjective scores or grades were used as criteria for evaluation of the birds. Hurry and Nordskog (1953) pointed out that about 20% of the variance in experimental error was found to

*Addendum 1.

be due to errors in grading committed by the grader. For this reason, it was felt that a tangible criterion is necessary to deal with the hereditary aspect of feathering and an objective system of scoring rather than a subjective score system, as used in many studies, is required.

The review of the literature shows that back score has been one of the major factors in the criterion of selection for birds' feather cover.

However in this experiment, the following scoring scheme was used, as illustrated in Figure 1.

1- No feathers over back except juvenile feathers.

2- A mixture of new sheath feathers and juvenile feathers.

3- Sheaths of new feathers spread all over the bird's back.

4- Most of the sheaths opened.

5- All back area not completely covered by new feathers.

6- The bird's back feathered all over.

Back score and the following linear measurements were taken at 23 days of age for females and 24 days of

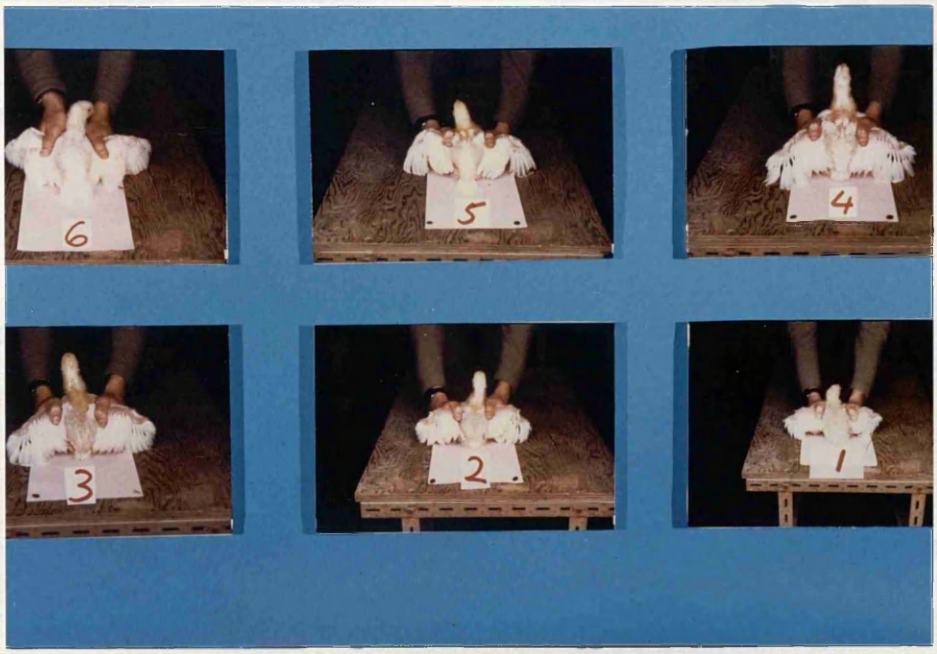


Figure 1. Subjective score taken at 24/25 days of age (1 = poorly feathered; 6 = fully feathered).

age for males; The length of primary number two and also secondary number two of the right wing of the bird from the base of the feather to the furthest point of emergence. All the linear measurements were recorded in millimetres.

However, as back score is a subjective measurement, the following formula was used to make a predicted back score as a criterion of selection which was adjusted for the above mentioned linear measurements.

$$Y = a + b_1x_1 + b_2x_2$$

where:

Y= Predicted back score of the individual;

a= intercept;

b_1= partial regression coefficient of primary length;

x_1= primary length;

b_2= partial regression coefficient of secondary length;

x_2= secondary length;

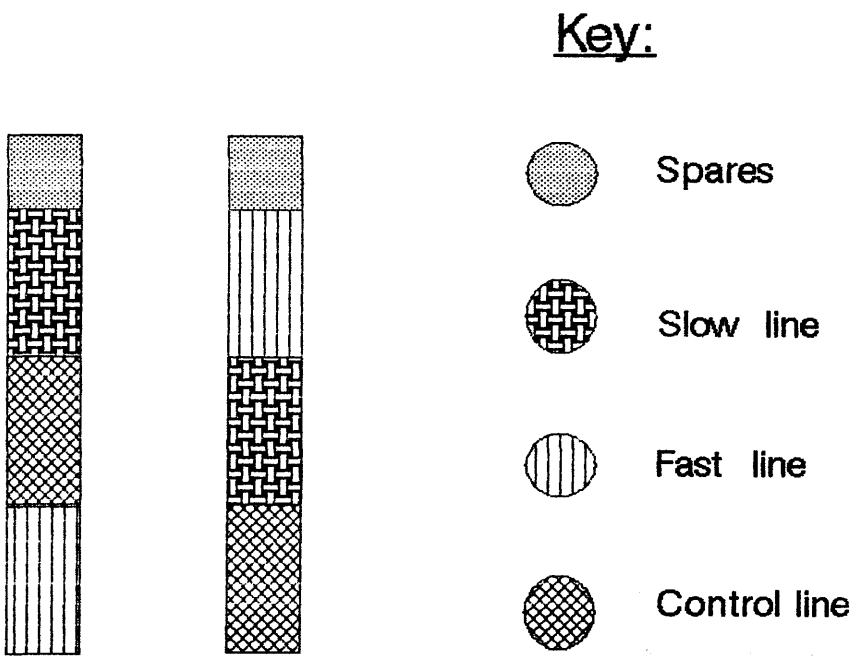
The model was used within sex, then the calculated values were ranked and the best feathered extreme group (line) was designated as "fast feathering" and the other extreme group as "slow feathering".

2.1.3 Management After Selection

All selected males and females were kept in separate pens up to 16 weeks of age. Due to restricted accommodation in laying and cockerel houses, a small proportion of the pullets and cockerels pedigreed were discarded at random within each line on the day of transferring birds to the individual bird cages at 16 weeks of age. However, at this stage, the females were caged individually in a laying house while the males were moved to a different house and caged individually. The laying house was windowless and ventilated through a glass fibre ceiling. It contained two banks of three tiers of Thornber cages (Thornber cages, Lancs), the outer face of each bank having 180 single bird cages of which 144 on each side were directly used in the experiment and the remainder were used to keep the spare birds. The experimental cages on each side were divided into three groups and the groups were randomly assigned for each line. Then 48 hens from each line were randomly assigned to each group of cages (Figure 2).

The cages used were 24.5 cm wide and 47.0 cm long and a plastic-type feeder trough was located in the front of the cages. The feeder trough was partitioned for each cage to make the birds unable to eat from the feed trough of the neighbouring birds. Each cage was designed to contain at least one "nipple" type waterer.

Figure 2. layout of the banks for different lines in the laying house



A V-shaped plastic trough ran below the nipple line to catch drips.

The temperature in the laying house was controlled by varying the ventilation rate in correspondence with the heat balance of the house. It was attempted to maintain the temperature at 21^{o}C in the house.

The lighting when the birds were housed had to be set to supply 12 hours of light per day (12L : 12D) because the interior cages of the banks were occupied by the layers of another experiment. Then, day-length was increased by 20 minutes per week to 17 hours, at which level it was held constant. Light was provided by 40 watt bulbs.

The males' house was also windowless and ventilated by two extractor fans. It contained on each of the two side walls a bank of single wooden cages. These were 4 m apart, facing each other. On the end wall, between these, was a bank of two tiers of cages. All banks were backed on to the walls of three sides of the house approximately 75 cm above the ground. The house contained 76 single cages in all. The first 24 single cages on either side were used directly in the experiment and the remainder were used to keep spare birds. The experimental cages on each side were divided into three groups and then each group was randomly assigned for each line. Then eight cockerels from each

line were randomly assigned to each group of cages (Figure 3).

Each cage was designed to contain one "cup" type drinker and a U-shaped plastic trough ran below the cups to collect waste water. A wooden U-shaped feeder trough was partitioned for each cage and located in the front of the cages. Cage floor was covered with wood shavings and it was cleaned regularly if wet.

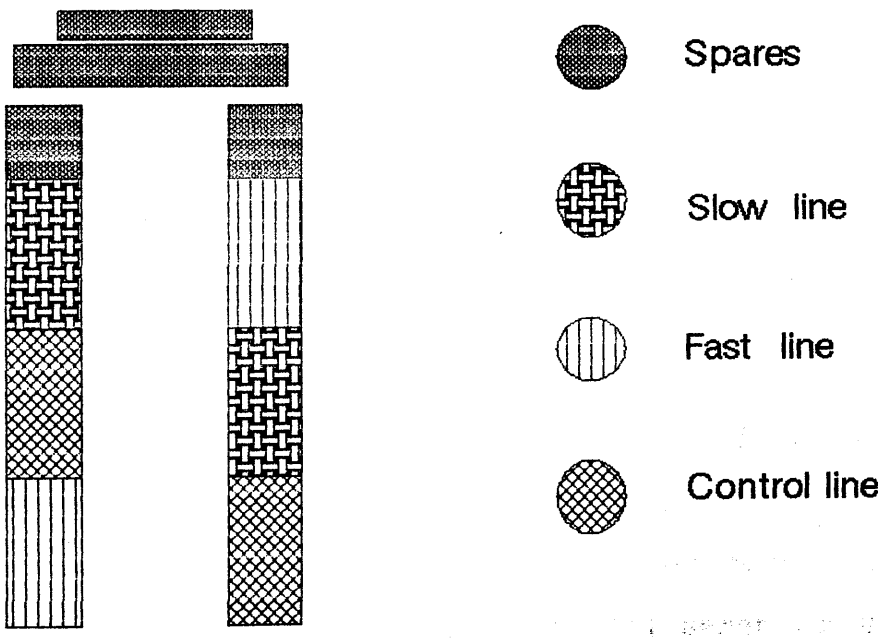
The house temperature was thermostatically controlled through the ventilation rate and the aim was to keep the temperature at 18°C. A second thermostat controlled supplementary heaters to maintain 18°C.

It should be noted that the same light pattern was employed for the cockerels as for females.

At the beginning of the pre-production period, hens were switched from the grower ration to a commercial breeder ration called "Broiler Breeder 170 meal" in mash form, while the males continued to get the grower ration. Both sexes were fed in a restricted way according to schedule (Appendix V).

Beginning with the first egg produced, individual production was recorded daily and only hens which produced more than one egg, within two weeks prior to 27 weeks of age, were saved to be the parents of the next generation offspring. Likewise, at the same age only

Figure 3. layout of the cockrel's house for different lines



those males that, by milking, showed production of a drop of semen were assigned to be a sire. Concurrently, all unsuitable birds were replaced with the spare birds. From this practice, a phenotypic selection for eggs and semen production was applied on the birds which were already selected for feathering. Egg collection was started, at 30th week of flock age, in order to progeny test the first group of broiler offspring.

2.2 Broiler Production From the Selected Base Population

Because the mean value of broiler progeny could show the criterion of selection of their parents, a batch of broilers was produced from selected birds of each generation.

A total of 16 males and 96 females from each line were used as the parents of the broiler progeny. In practice, two batches of 48 females of each line were assigned to be inseminated by pooled semen of 8 males from the same line. When the flock was 30 weeks old, the first artificial insemination was carried out. This was conducted by following a method similar to that described by Lake and Stewart (1978) for chickens. The volume of inseminated semen per hen, herein, varied but was almost always greater than the minimum amount generally recommended (0.05 cc) for chickens. Two days after the first insemination, a second artificial insemination was employed, to maximise fertility.

Subsequent inseminations were conducted three times in the two subsequent weeks.

From the third day after the first insemination the eggs from all the individual hens were collected daily together on the basis of their line. During the next two weeks, every afternoon, all the collected eggs were observed to see if they were clean. Dirty eggs were brushed and then all the eggs were moved to a cold room at 11-12^{o}C and 75% relative humidity. Approximately 24 hours prior to incubation, the eggs were brought to room temperature and sorted out by lines. Then, they were fumigated to sterilise the shells. The eggs were then incubated for 18 days at 99.5 F (37.3^{o}C) and 53% relative humidity. It should be noted that at 7 and 18 days of incubation all eggs were candled to withdraw infertile eggs and dead embryos from the trays. On the 19th day, all eggs were transferred to hatching trays according to their line. The unit was regulated to operate at 99.0 F (36.8^{o}C) and 71% relative humidity. On the 22nd day of incubation, the hatch was taken off and all chickens were vent-sexed and vaccinated against Infectious Bronchitis. Then chickens of each line within sex were grouped in 3 replicates of 75 birds to make a total of 18 groups. A random sample of 10 birds of each group was wing banded for further measurements.

2.2.1 Growing Period

All day-old chicks were transported to a controlled environment broiler house which was partitioned to form 18 pens. The floor area of each pen was 5.57 m^2 and a 10 cm layer of wood shavings was spread evenly over the floor. Each group of six pens was allocated at random to each of the 3 replicates. So, each replicate contained all lines by sex as illustrated in Figure 4.

The chicks were supplied with a photoperiod of 23 hours light and one hour darkness during the course of study. The light, which was provided by 100W bulbs, was controlled by dimmers to provide suitable light intensity. From day-old until seven days of age, light intensity was 20 lux and then, it was reduced to an intensity of 2 lux, which was maintained until the end of the trial.

The management plan was to have a temperature of 32.5^{o}C at day-old and decrease it steadily to 21^{o}C at 21 days of age and then keep it constant up to 7 weeks of age which was the end of the growing period, but, due to insulation problems, the outside temperature had a slight effect on the inside temperature. Ventilation was regulated by thermostatically controlled pressurising fans under the roof and sidewall air outlets. The birds in each pen had access to an automatic bell-shaped

Figure 4. The layout of the broilers production experiments

S – Ma	F – Fe
C – Fe	C – Ma
F – Ma	S – Fe

S – Fe	F – Ma
C – Ma	C – Fe
F – Fe	S – Ma
S – Ma	F – Fe
C – Fe	C – Ma
F – Ma	S – Fe

Keys:

F : Fast line
S : Slow line
C : Control line

Ma : Male
Fe : Female

drinker as well as two manually filled tubular feeders.

The chicks were fed on a commercial broiler ration ad libitum (Dalgety Agriculture Limited). Broiler Starter Crumbs were fed from day-old at a level of 0.5 kg/bird. This was followed by Broiler Grower Pellets at a level of 1.0 kg/bird. Broiler Finisher Pellets were fed ad libitum up to three days before the end of the trial and Withdrawal Pellets were fed for the last three days. The composition of the feeds is shown in Appendix VI.

2.2.2 Recordings

At 24 days of age the following measurements were taken of the wing banded birds in the pens:- subjective back score for feather cover; length of primary and secondary feathers and body weight, all as defined under Selection Procedures. An extra measurement, which was the actual length of tail central feathers from the extreme tip of the pygostyle to the end of the longest feathers, was also obtained. These wing-banded birds were recorded individually, while the bulk weight of the remainder of the birds in the pen was also recorded. At the end of weeks five and seven of the trial all the birds in each pen were weighed in bulk. In order to calculate the feed conversion ratio, on the same recording days, feed intakes were recorded for each pen.

At 49 days of age the birds which were wing-banded at day-old as the random samples were removed from the pens and kept in separate pens for approximately 12 hours. Within that time, they had access to water only. They were slaughtered after the individual starved weight was recorded. The following records were measured on each dead body; plucked weight, weight of abdominal leaf fat plus that surrounding the gizzard, and lastly the washed carcass weight.

2.3 Breeding of Generation One

In each line, a total of 16 potential males and 96 potential females were used as the parents of the next generation. Consequently, six females were assigned to mate with one male to constitute a particular family.

When the flock was 38 weeks old a mating was carried out by artificially inseminating each hen with semen from a specific sire. This was conducted by the same procedures as mentioned for production of broiler progeny. It should be noted that due to insufficient semen production of a few sires to cover all the females which they were assigned to, when the second artificial insemination was employed two days later the priority was for those who did not get any semen at the first insemination. All subsequent matings, however, were

conducted every five days and two hatches of pedigreed chicks were obtained.

The pedigreed eggs from each individual hen were collected daily and the cage number was marked on the shell and stored at 12^{o}C in bags under nitrogen from the time of collection to the beginning of incubation. To produce the first hatch, the eggs were kept for 14 days and in the case of the second one they were stored for 10 days. Approximately 24 hours prior to incubation, the eggs were brought to room temperature and sorted out by dam cage number. After sterilisation of egg-shells by formaldehyde fumigator, they were incubated for 18 days at 99.5 F and 53% relative humidity. Then, eggs from each dam were placed under one or two metal pedigree enclosures on hatching trays. The hatcher temperature was 99.0 F with 70% relative humidity. On the 22nd day of incubation the hatch was taken off and all chicks were wing-banded according to pedigree by sires and dams.

All day-old chicks of each hatch were transported to the same house where the base generation was recorded. The aim was to have the same conditions for rearing as for the base generation. Overall a total of 1286 pedigreed chicks were obtained in this generation at day-old.

2.4 Selection and Subsequent Mating

Pre-analysis of data of another experiment of mine (Appendix VI) showed more than 90% correlation between back score and tail length at 3 or 4 weeks of age in broilers. So, it encouraged us to move forward to a more objective measurement for the next two generations. However, the following formula was employed to be the criterion for selection of fast feathering birds within the fast line and slow feathering ones among the slow line.

$$Y = a + b_1x_1 + b_2x_2 + b_3x_3$$

where:

Y= predicted tail length of the individual;

a= intercept;

b_1= partial regression coefficient of back score;

x_1= back score;

b_2= partial regression coefficient of primary length;

x_2= primary length;

b_3= partial regression coefficient of secondary length;

x_3= secondary length;

In generation one and two, two hatches were taken off. So, the model was used within sexes and hatches within each extreme line. It should be noted that the

number of selected birds was the same as in the first generation and for elimination of hatch effect, the number of selected birds from each hatch within sex was directly related to the proportion of that particular hatch in all live birds at the time of recording. Selection was performed within each of the divergent lines.

Prior to beginning any artificial insemination for production of pedigree stock, matings were made on paper, based on pedigree information. To prevent inbreeding, restriction were no brother/sister mating and no related dams in a sire mating.

When the flock was 27 weeks old, the first mating for broiler progeny production was carried out. The mating procedure and broiler production programme were the same as in the previous broiler production except for the number of chickens in each pen, which was 50 birds.

When the flock was 37 weeks old, a mating procedure was carried out to produce a new pedigree generation. To raise this generation which was called the second generation, temperature, lighting and the other rearing arrangements were managed so as to provide environmental conditions that were as similar as possible among generations. A total of 1989 day-old pedigree chicken were obtained.

Feathering measurements and body weight were recorded at 24 days of age for females in hatch one and at 25 days of age for males and all the birds of hatch two which were alive, using the same methods and tools as for the birds of the previous generations.

When the flock was 42 weeks old, a special mating was performed to produce some broiler chicks for an experiment which was aimed at comparing responses of the created lines in respect of growth and carcass composition under high ($30^{o}C$) or normal ($20^{o}C$) temperatures.

2.5 Temperature Experiment

This experiment was designed to study the responses of created fast and slow feathering lines under temperatures of $30^{o}C$ compared to $20^{o}C$.

Over 800 chicks were produced from three lines of generation two parent stock, using the same procedures as were used to produce broiler progeny of the same generation. All day-old chicks were vaccinated and sexed. Then, the chicks of each line within sex for two temperatures were grouped in two replicates of 33 birds to make a total of 24 groups. One replicate of the birds under each temperature treatment were wing-banded for further measurements.

All the birds were transported to an environmental controlled house with four rooms, each room containing six pens as illustrated in Figure 5.

Each room was considered as a replicate for the temperature treatments. Wood-shavings were used as litter for pens and stock density of 12.5 birds per square metre was used so that space was not limiting to growth.

The chicks were given a photoperiod of 23 hours light and one hour darkness during the course of study. The light was supplied by 40W bulbs. The light intensity was controlled by dimmers to provide light intensity of 20 lux within the first week of experiment and it was reduced to an intensity of 2 lux which was maintained up to the end of experimental period.

An attempt was made to provide a temperature of 32.5^{o}C at day-old decreasing steadily to 30^{o}C at day-six in all the experimental rooms. In the two rooms which were assigned to a high temperature, a temperature of 30^{o}C from day-six, was constant until the end of the experimental period at 49 days of bird age. In the other two rooms which were assigned for a temperature of 20^{o}C, the temperature from day-eight was decreased steadily to 20^{o}C at 17 days of bird age, then it was constant up to the end of the trial period. The ventilation rate in the

Figure 5. The layout of the temperature experiment

Room 1 20°C

C – Ma	F – Fe
S – Fe	S – Ma
F – Ma	C – Fe

Room 3 30°C

S – Ma	C – Fe
F – Fe	F – Ma
C – Ma	S – Fe

Room 2 20°C

C – Ma	F – Fe
S – Fe	S – Ma
F – Ma	C – Fe

Room 4 30°C

S – Ma	C – Fe
F – Fe	F – Ma
C – Ma	S – Fe

Keys:

F : Fast line
S : Slow line
C : Control line

Ma : Male
Fe : Female

rooms was regulated by thermostatically controlled pressurising fans which were provided in the roof. Birds in each pen had access to an automatic bell-shaped drinker and a manually filled tubular feeder.

The chicks were fed ad libitum on a commercial broiler ration (Dalgety Limited). From day-old, Broiler Starter Crumbs at a level of 0.5 kg/bird were fed. It was followed by Broiler Grower Pellets at a level of 1.0 kg/bird. Then, the birds were given Broiler Finisher Pellets which were continued up to 3 days before the end of the experiment. For the last 3 days of the experiment Withdrawal Pellets were fed to the birds. The composition of the feeds is shown in Appendix VII.

2.5.1 Recordings

When the broilers were 26 days old, the following measurements were taken of wing-banded birds from a replicate of each temperature treatment: Subjective back score for feather cover and primary, secondary and tail length, as was described previously. Also body weight was recorded individually for these birds. In the other replicate of each temperature treatment bulk body weight was recorded for each pen. The same weighing procedures were employed at weeks five and seven. In order to calculate feed conversion ratio, feed intakes for each pen were recorded on the same recording day.

At 49 days of age, 15 wing-banded birds of each pen were removed at random and kept in an empty pen in the same room for approximately 12 hours. During this time, the birds had access to water only. At 10 a.m. on the next day, prior to slaughter, the starved weight of each bird was recorded. Then the following weight measurements were recorded for each bird: plucked weight, abdominal fat including gizzard fat, and carcass weight after it was washed.

2.6 Statistical Procedures

In order to analyse the collected data from the two generations only those birds which survived up to 24/25 days of age and had records of measurements were subject to the statistical analysis.

The selection differential was calculated for back score, linear measurements and body weight. It should be noted that body weight was considered as an indirect effect of selection for body feather cover. However, the selection differential was computed as the deviation of the average of selected individuals from the average of the population in which they were hatched. It was also necessary to obtain the response to selection of each trait, within each generation. To do this the deviation of the appropriate means of each selected line from the

control line within generations were calculated. It should be noted that the calculations were carried out for the selected males and females separately.

2.6.1 ANOVA of the Response to Selection in Generations One and Two

Due to the unequal number of observations in subclasses and obtaining unbiased estimates of variance components (Henderson 1953), data of generation one and two were analysed by the least-squares procedures as outlined by Harvey (1975). In order to analyse back score, feather linear measurements and body weight at 24/25 days of age, constants were fitted for the effect of line, sire within line, dam within sire within line, sex of chick and hatch, and interaction between line and sex, line and hatch, and sex and hatch using the following mathematical model:

(Model 1)

$$Y_{ijklmn} = U + A_i + b_{ij} + c_{ijk} + D_l + E_m + (AD)_{il} + (AE)_{im} + (DE)_{lm} + e_{ijklmn}$$

b_{ij}, c_{ijk} and e_{ijklmn} were random effects while the others were fixed effect. Interaction of b_{ij} and c_{ijk} were assumed to be non-existent.

Where:

Y_{ijklmn} was the nth measurement in the mth hatch of the lth sex of chick from the kth dam and jth sire in the ith line;

U was the mean that would exist if all classes had equal numbers;

A_i was the effect of the ith line of chicken;

b_{ij} was the effect of the jth sire nested within the ith line;

c_{ijk} was the effect of the kth dam mated to the jth sire nested within ith line;

D_l was the effect of the lth sex of chick;

E_m was the effect of the mth hatch;

$(AD)_{il}$ was the interaction between Ai and Dl;

$(AE)_{im}$ was the interaction between Ai and Em;

$(DE)_{lm}$ was the interaction between Dl and Em; and

e_{ijklmn} was the random error associated with the nth observation in the mth hatch of the lth sex of chick from the kth dam and jth sire in the ith line.

2.6.2 ANOVA of the Selection Response in Two Progeny Tests

In order to analyse the data on feed-intake, body weight and feed conversion ratio at 24 days, and five and seven weeks of age, and back score and primary, secondary and tail feather length at 24 days of age as well as starved weight, plucked weight, carcass weight and abdominal fat weight constants were fitted for the

effect of replicate, line and sex using the following model:

(Model 2)

$$Y_{ijkl} = U + a_i + B_j + C_k + e_{ijklmn}$$

a_i and e_{ijkl} were assumed to be random effects. Interactions were assumed to be non-existent.

Where:

Y_{ijkl} was the lth measurement in the kth sex of chick of the jth line in the ith replicate;

U was the overall mean;

a_i was the effect of the ith replicate;

B_j was the effect of the jth line;

C_k was the effect of the kth sex of chick; and

e_{ijkl} was random error.

Further analysis was carried out for 49-day body weight in order to adjust for cumulative feed intake and also abdominal-fat in order to adjust for starved weight. The following model was used:

(Model 3)

$$Y_{ijkl} = U + a_i + B_j + C_k + b(X_{ijkl} - X) + e_{ijklmn}$$

Where:

a,B,C and e were as defined previously; and

U was the population mean when X was equal to zero;

X_{ijkl} was the lth cumulative feed intake for the adjustment of 49-day body weight, and starved weight for the adjustment of abdominal-fat weight;

$\bar{X}$ was the arithmetic mean of X_{ijkl}; and

b was partial regression of Y_{ijkl} on cumulative feed intake or starved weight depending on the case.

2.6.3 ANOVA of the Temperature Experiment

In this experiment which dealt with temperature the same sort of measurements which were considered for the broiler progeny test were used. The following mathematical model was used to analyse the data:

(Model 4)

$$Y_{ijkl} = U + A_i + B_j + C_k + (AB)_{ij} + (AC)_{ik} + (BC)_{jk} + e_{ijkl}$$

Where:

Y_{ijklmn} was the measurement of the lth individual of the kth sex of chick of the jth line under the ith temperature;

U was the overall mean;

A_i was the effect of the ith temperature;

B_j was the effect of the jth line;

C_k was the effect of the kth sex of chick;

$(AB)_{ij}$ was the interaction between Ai and Bj;

$(AC)_{ik}$ was the interaction between Ai and Ck;

$(BC)_{jk}$ was the interaction between Bj and Ck;

e_{ijklmn} was the random error effect.

In order to adjust back score and tail length for body weight at 26 days of age, and adjust 49-day body weight for cumulative feed intake, and abdominal-fat weight for starved weight the following mathematical model was used:

(Model 5)

$$Y_{ijkl} = U + A_i + B_j + C_k + (AB)_{ij} + (AC)_{ik} + (BC)_{jk} + (ABC)_{ijk} + b(X_{ijkl} - X) + e_{ijkl}$$

Where:

A,B,C,AB,AC,BC and e were as defined previously; and

U was the population mean when X was equal to zero;

$(ABC)_{ijk}$ was the interaction between Ai and Bj and Ck;

X_{ijkl} was the lth body weight at 26 days of age

for back score and tail length, and cumulative feed intake for 49-day body weight, starved weight for abdominal-fat weight.

$\bar{X}$ was the arithmetic mean of X_{ijkl}; and

b was partial regression of Y_{ijkl} on body weight at 26-days of age or cumulative feed intake or starved weight depending on the case.

2.6.4 Heritability Estimates

To estimate heritability of back score, and primary, secondary and tail length, and body weight at 24/25 days of age within a given generation, Model 1 was used. Calculations were based on full-sib analysis. The estimates were computed on three bases; namely, from the sire and dam components combined, from the sire components and from the dam components. The sire and dam components were estimated by the indirect procedure as defined by Harvey (1970). Estimates of sire, S, dam's, D, and error, $\acute{o}^2_e$, variance components were made using Mixed Model Least-Squares and Maximum Likelihood Computer Programme, PC-1 Version of LSMLMW by Harvey (1987) on the Amstrad PC 1512 at Computer Unit at The West of Scotland Agricultural College, Auchincruive.

Heritability estimates for sire, h^2_s, for dam, h^2_d, and sire plus dam, h^2_{s+d}, which are considered as a fraction of total variance were expressed by the following notations:

$$1.\quad h^2_S = \frac{4\,\sigma^2_s}{\sigma^2_s + \sigma^2_{d:s} + \sigma^2_e}$$

$$2.\quad h^2_D = \frac{4\,\sigma^2_{d:s}}{\sigma^2_s + \sigma^2_{d:s} + \sigma^2_e}$$

$$3.\quad h^2_{S+D} = \frac{2\,(\sigma^2_s+\sigma^2_{d:s})}{\sigma^2_s + \sigma^2_{d:s} + \sigma^2_e}$$

where:

σ^2_s = between sires components of variance,

$\sigma^2_{d:s}$ = between dams within sires components of variance,

σ^2_e = full-sibs variance components.

The standard errors of the heritability estimates were computed by an approximation method since these were computed from full-sibs, from paternal half-sibs and from maternal half-sibs, as if the analysis was simply a "between family" and "within family" analysis

with unequal numbers but with no adjustment for fixed effects. Therefore, the standard errors should be considered as minimum estimates of the true standard errors. The formula given by Swiger et al. (1964) were modified (Harvey 1987) to compute the standard errors.

2.6.5 Correlations Between Feathering and Correlated Traits

The analysis of variance schemes were extended in the computer program to include covariance between the feathering and the correlated traits: body weight, back score, and primary, secondary and tail length at 24/25 days of age. The components of covariances were determined on the basis of sire, s; dams within sires, d:s; and full-sib, e. The formulae were modified (Harvey 1987) to compute the estimation of phenotypic, $r_{P(tt')}$; genetic, $r_{G(tt')}$; and environmental, $r_{E(tt')}$, correlations from the variance covariance analysis. These formulae were:

1. Phenotypic correlation

$$r_{P(tt')} = \frac{\sigma_{s(tt')} + \sigma_{d:s(tt')} + \sigma_{e(tt')}}{\sqrt{\sigma^2_{s(t)} + \sigma^2_{d:s(t)} + \sigma^2_{e(t)} \quad \sigma^2_{s(t')} + \sigma^2_{d:s(t')} + \sigma^2_{e(t')}}}$$

where t refers to the t^{th} trait and t′ refers to another trait.

2. Genetic correlation

$$\text{a:}\quad r_{G(tt')\,S} = \frac{\sigma_{s(tt')}}{\sqrt{\sigma^2_{s(t)} * \sigma^2_{s(t')}}}$$

$$\text{b:}\quad r_{G(tt')\,D} = \frac{\sigma_{d:s(tt')}}{\sqrt{\sigma^2_{d:s(t)} * \sigma^2_{d:s(t')}}}$$

$$\text{c:}\quad r_{G(tt')\,S+D} = \frac{\sigma_{s(tt')} + \sigma_{d:s(tt')}}{\sqrt{\{\sigma^2_{s(t)} + \sigma^2_{d:s(t)}\}\{\sigma^2_{s(t')} + \sigma^2_{d:s(t')}\}}}$$

3. Environmental correlation

$$\text{a:}\quad r_{E(tt')\,S} = \frac{\sigma_{e(tt')} - \frac{c+b}{a}\sigma_{s(tt')} + \sigma_{d:s(tt')}}{\sqrt{\{\sigma^2_{e(t)} - \frac{c+b}{a}\sigma^2_{s(t)} + \sigma^2_{d:s(t)}\}\{\sigma^2_{e(t')} - \frac{c+b}{a}\sigma^2_{s(t')} + \sigma^2_{d:s(t')}\}}}$$

$$\text{b:}\quad r_{E(tt')\,D} = \frac{\sigma_{e(tt')} - \frac{c+a}{b}\sigma_{d:s(tt')} + \sigma_{s(tt')}}{\sqrt{\{\sigma^2_{e(t)} - \frac{c+a}{b}\sigma^2_{d:s(t)} + \sigma^2_{s(t)}\}\{\sigma^2_{e(t')} - \frac{c+a}{b}\sigma^2_{d:s(t')} + \sigma^2_{s(t')}\}}}$$

$$c: r_{E(tt')\ S+D} = \frac{\sigma_{e(tt')} - \frac{c}{b+a}\{\sigma_{d:s(tt')} + \sigma_{s(tt')}\}}{\sqrt{[\sigma^2_{e(t)} - \frac{c}{b+a}\{\sigma^2_{d:s(t)} + \sigma^2_{s(t)}\}]\ [\sigma^2_{e(t')} - \frac{c}{b+a}\{\sigma^2_{d:s(t')} + \sigma^2_{s(t')}\}]}}$$

where a is the decimal percentage of the genetic variance in o^2_s, and b is the decimal percentage of genetic variance in $o^2_{d:s}$ and c is the decimal percentage of genetic variance among full-sibs, i.e., in o^2_e. It was assumed that within each line in each generation, the population was randomly mated. So, due to this assumption the value of a and b would be equal to .25 and c equal to .50.

It should be noted that when a estimate of the variance component was negative, it set to zero for the related computation.

The approximate standard errors for genetic correlations were computed from procedures described by Tallis (1959). The procedures used to compute approximate standard errors do not account for the adjustments made for fixed effects. Therefore, the exact standard errors may be larger than those reported (Harvey, 1987).

Chapter Three: Results and Discussion

The data obtained in this study, two generations of selection, were such that total variance among individuals was measured in the same location and environment. Throughout the experiment the same persons were involved in scoring back feather cover and carrying out the measurements of feather length. Thus the experiment was carefully designed to yield as unbiased estimates as possible. The number of birds involved in the experimental selection procedures and the percentage of the selected birds within generation, line and sex are shown in Table 1.

3.1 Asymmetric Response

Basic feather traits and body weight for fast and slow feathering is presented in Table 2. On average the result of two generations of selection for fast feathering showed a gain of .93 and .74 score units of back score; 3.47 and 1.30 mm of primary length; 9.69 and 5.51 mm of secondary length; and 5.19 and 7.64 mm of tail length, for males and females, respectively, whereas for the slow feathering a loss of .75 and .66 units of score of back score; 5.48 and 4.04 mm of primary length; 7.20 and 6.50 mm of secondary length;

Table 1. Number of birds involved in selection procedures within generation, line and sex and the percentage which was selected from each sub-group.

Generation of selection		Male	Female
Base			
	Line:		
	Fast	552 (%5.4)[a]	422 (%35.5)
	Control	582 (%5.2)	572 (%26.2)
	Slow	552 (%5.4)	422 (%35.5)
1			
	Line:		
	Fast	208 (%14.4)	212 (%70.8)
	Control	126 (%23.8)	144 (%100.0)
	Slow	199 (%15.1)	235 (%63.8)
2			
	Line:		
	Fast	314 (%9.6)	307 (%48.8)
	Control	307 (%9.8)	269 (%55.8)
	Slow	240 (%12.5)	308 (%48.7)

[a] Percentage of selected birds in parentheses.

and 3.48 and 5.30 mm of tail length, for males and females, respectively. The dissimilar response in the divergent lines from bi-directional experiments has been investigated by Falconer (1953). He ascribed the asymmetric condition to differences in the gene frequencies for those genes governing the traits. Falconer (1981) also suggested that the asymmetrical response in divergence between upwards and downwards selected lines are consequences of change in some parameters such as phenotypic standard deviations and covariances, due to the selection applied. Clayton et al. (1957) from a bi-directional experiment for high and low sternital bristle number in Drosophila melanogaster, have observed an asymmetrical response in that trait. They attributed the condition to the phenomenon of gene drift when the genetic correlation is low. Siegel (1962) attributed the cause to some differences in the genetic variance or heritabilities for the traits. Another possible cause for the asymmetry reported by Falconer (1981) is the different selection differentials in the divergent lines which will be discussed later in this section.

It is worth noting that the data in Table 2 indicate that the observed changes in body weights were likely to yield an irregular fit in both sexes. Related reports concerning body weight in chickens by Maloney and Gilbreath (1966), Festing and Nordskog (1967) and

Table 2. Effect of divergent selection for fast (F) and slow(s) feathering as deviated from the control (C) line on primary, secondary and tail length, and back score and body weight in different generation populations.

Sex	Generation of selection	Primary Length (mm)			Secondary length (mm)			Tail length (mm)			Back score			Body weight (g)		
		C	F	S	C	F	S	C	F	S	C	F	S	C	F	S
Male																
	base	76.59	-	-	52.36	-	-	-	-	-	1.80	-	-	318.2	-	-
	1	84.05	+2.10	-1.10	61.89	+6.40	-2.59	18.67	+3.15	- .88	2.70	+ .79	- .08	485.1	+14.9	-8.1
	2	79.48	+3.47	-5.48	55.0	+9.69	-7.20	14.86	+5.19	-3.48	3.13	+ .93	- .75	418.6	+21.9	-19.4
	Average		+2.78	-3.29		+8.04	-4.89		+4.17	-2.18		+ .86	- .42		+18.4	-13.7
Female																
	base	77.80	-	-	61.86	-	-	-	-	-	2.34	-	-	291.2	-	-
	1	89.07	+1.78	+.13	79.25	+4.41	-1.15	30.82	+6.86	-2.44	4.62	+ .56	- .20	498.9	+12.1	+1.1
	2	80.64	+1.30	-4.04	65.10	+5.51	-6.50	20.50	+7.64	-5.30	3.70	+ .74	- .66	380.5	+ 8.0	-21.5
	Average		+1.54	-2.08		+4.96	-2.82		+7.25	-3.87		+ .65	- .43		+10.0	-10.2

Carte and Siegel (1968) indicated that in divergent selection experiments an asymmetrical response is likely to be realised fairly frequently. This is to say, the progeny of positive selection line gain more than the progeny of negative selection line lose. Also, they concluded that male individuals gain or lose more than female individuals do, in divergent lines. In this study, although the main selected trait was feathering rate, not body weight, it can be observed from Table 2, that the fast line compared to the control gained more than the slow line lost, except in the case of females in generation two where slow featherings lost much more than fast featherings gained (-21.5 vs. +8.0 g). It should be noted that in the case of females in the first generation, both fast and slow feathering, compared to the control group, had a positive response to selection. The positive selection line gained more than the negative selection line did (+12.1 vs. +1.1 g). It also should be noted that, as Table 2 shows, as an effect of divergent selection, the male individuals on average gained or lost more than the female individuals did. The figures were on average +18.4 and -13.8 g for males and +10.0 and -10.2 g for females. However, these findings are consistent with the conclusions of the above investigators.

Let us consider the response of feathering to selection in the two sexes. The average amount of

response in the fast line for back score, secondary and tail length was generally two times that of the slow line while the average amount of response for primary length between the two lines was comparatively much closer than the other feathering traits. Accordingly, one or more of the possible reasons for the asymmetric responses of divergent lines for selected and controlled traits may be the cause of the asymmetrical responses for feathering and body weight in the two divergent lines of this study. However, the most tangible reason for this condition is believed to be the different selection differentials in the fast and slow feathering lines.

An interesting point which should be noted is that after many generations of selection for body weight and the correlated improvement in feathering there is still some more room to improve feathering rate by direct selection for feathering traits. In support of the argument, it can be noted that Siegel et al. (1957a) was investigating heritability of back score at 5,7 and 12 weeks of age while in the present broilers it is impossible to measure back score after about 5 weeks of age. Currently it is necessary to measure back score sometimes between three and four weeks of age. And yet, it has been shown that it is still possible to accelerate feathering in positive direction by a direct selection for feathering traits. In terms of the physiology of thermoregulation the evidence that

feathering can still be improved means that the energy cost of thermoregulation during the brooding period may be reduced. Consequently, the rate of decrease of brooding temperature could be greater in fast feathering birds which means saving in fuel cost.

3.1.1 Selection Differential

Selection differentials for back score, body weight, and primary, secondary and tail length are shown in Table 3. Overall the average selection differential for males in all considered traits was higher than for females which could be due to the lower proportion of selected males (Table 1). Asymmetric responses between the fast and slow lines were also observed in selection differentials (Table 3). The average selection differential in back score and tail length was higher in the fast line, while the average selection differential was higher for primary and secondary length in the slow line. Since the origin of the basal population was the slow feathering line the positive asymmetric response of the average selection differential for back score and tail length in the fast line, compared to the slow line, was expected, whereas the negative asymmetric response of the primary and secondary length was not expected. Falconer (1981) pointed out that the selection differential may differ between upward and downward

Table 3. Selection differentials[a] obtained in the divergently selected birds for fast (F), slow (S) and control (C) feathering lines.

Sex	Generation of selection	Primary Length (mm)			Secondary length (mm)			Tail length (mm)			Back score			Body weight (g)		
		C	F	S	C	F	S	C	F	S	C	F	S	C	F	S
Male																
	base	-.95	+8.73	-9.17	-2.57	+13.07	-25.42	-	-	-	-.16	+1.66	-.80	-4.3	+63.7	-29.5
	1	-.03	+4.69	-7.53	+ .23	+ 9.20	-10.58	+.09	+10.00	-4.58	+.19	+1.33	-.74	-2.9	+88.5	-36.1
	2	+1.22	+4.58	-16.77	+2.10	+11.91	-25.10	-.29	+13.98	-5.81	-.16	+1.17	-.35	+6.6	+12.7	-47.3
	Average	+ .08	+6.0	-11.16	- .08	+11.39	-20.37	-.10	+11.99	-5.20	-.04	+1.39	-.96	- .2	+55.0	-37.6
Female																
	base	+ .45	+3.44	-5.62	- .70	+ 5.01	- 7.27	-	-	-	-.05	+1.14	-.90	-2.0	+32.0	-32.0
	1	+ .17	+1.03	- .72	+ .55	+ 2.52	- 2.03	+1.31	+ 4.10	-3.46	+.12	+ .24	-.28	+9.2	+32.7	- 5.3
	2	- .21	+2.43	-5.23	- .55	+ 5.04	- 8.63	+ .24	+ 6.60	-3.91	+.01	+ .73	-.97	-42.9	+28.2	-26.8
	Average	+ .14	+2.30	-3.86	- .23	+ 4.19	- 5.98	+ .78	+ 5.35	-3.68	+.03	+ .70	-.72	-11.9	+31.0	-21.4

[a]Express as a deviation of the average of selected birds from the average hatch mean of the population which they were born.

selected lines, due to an increase of variance which is as a result of the change in the mean. Considering this hypothesis, the data for primary and secondary length in Table 3 show that the means of the slow feathering line compared to the control, changed about two times more than those of the fast feathering line. This could be a possible reason for the higher selection differential in the primary and secondary length of the slow line.

3.2 Contribution of factors to trait variation in the first and second generation

3.2.1 Percentage of Variation For Each Factor

The percentage of variation accounted for by various factors affecting back score, body weight, and primary, secondary and tail length for the first and second generations are shown in Tables 4 and 5, respectively. In the mixed model analysis of variance the random effects, sire within line and dam within sire within line, were responsible for a large percentage of variation in both generations. The line effect which was considered as a fixed parameter in the analysis and could be taken as an indication of effectiveness of selection, showed no significant effect on body weight (which was not a parameter in the selection index) or on primary length (which was a component of the selection

Table 4. Contribution of line (L), sire within line, dam within sire within line, sex (S), hatch (H), and the interaction of L*S, L*H and S*H to the variation in back score, body weight, and primary, secondary and tail length in the first generation of selection (percentage of variation).

Source of valuation	Degree of freedom	Back Score	Body weight	Primary length	Secondary length	Tail length
Line (L)	2	4.91**	.32	.79	4.19**	3.98**
Sire within Line (S:L)	45	9.26**	21.26**	13.27**	9.67**	13.09**
Dam within (S:L)	190	16.29**	23.01**	25.59**	18.48**	14.75**
Sex (S)	1	31.06**	.01	6.45**	27.64**	23.67**
Hatch (H)	1	4.06**	13.39**	5.50**	2.72**	6.67**
L*S	2	.11	.09	.59**	.79**	.81**
L*H	2	.50	.71**	.20	.15	.49**
S*H	1	.02	2.59**	1.46**	1.01**	1.09**
Remainder	879					
Percentage of total variation accounted for by all the factors		65.77	61.38	53.86	64.67	64.56

** Significant at $P < .01$

Table 5. Contribution of line (L), sire within line, dam within sire within line, sex (S), hatch (H), and the interaction of L*S, L*H and S*H to the variation in back score, body weight, and primary, secondary and tail length in the second generation of selection (percentage of variation).

Source of valuation	Degree of freedom	Back Score	Body weight	Primary length	Secondary length	Tail length
Line (L)	2	21.58**	3.10*	8.97*	16.63**	20.11**
Sire within Line (S:L)	45	10.82**	17.68**	26.98**	21.39**	12.73**
Dam within (S:L)	219	14.56**	22.76**	18.69**	15.25**	14.74**
Sex (S)	1	3.48**	5.77**	.16*	8.22**	7.5**
Hatch (H)	1	.01	.02**	.82**	.37**	.56**
L*S	2	.20*	.06	.91**	.75**	.64**
L*H	2	.06	.24*	.05	.02	.02
S*H	1	.12*	.51**	.01	.14*	.02
Remainder	1471					
Percentage of total variation accounted for by all the factors		50.84	50.14	56.59	62.78	56.34

* significant at P < .05

** Significant at P < .01

index). However, line had a significant effect on the rest of the traits in the first, and on all of the traits in the second, generation. The contribution of line was 4.91, .32, .79, 4.19 and 3.98 per cent of variation for back score, body weight, and primary, secondary and tail length in the first generation, respectively. The contribution of line in the the second generation increased to 21.58, 3.10, 8.97, 16.63 and 20.11 per cent for the aforementioned traits, respectively. These increases could be due to the increases of variation within and/or between lines. However, generally it is expected that as selection continues within-line variations decrease. Considering this, it may be postulated that the observed increased variance could be mainly due to increases of between-line variation which is an indicator of effectiveness of selection as the selection was continuing. It should be noted that increases of between-line variation show wider differences between fast and slow lines.

3.2.2 Effect of Line, Sex and Hatch on Different Traits

3.2.2.1 Line Effect

Least-squares means and standard errors for the selected traits, feathering, and the unselected one, body weight, are presented by line, sex and hatch in Tables 6 and 7 for the first and second generations,

Table 6. Least-squares means and standard errors by line , sex and hatch for back score, body weight, and primary, secondary and tail length at about 24 days of age in the first generation.

Main effects		No. obs.	Back score	Body weight (g)	Primary length (mm)	Secondary length (mm)	Tail length (mm)
Overall means		1124	3.72±.07	479±7.5	86.2±.44	70.7±.67	24.6±.63
Line							
	Fast	420	4.12±.13 a	474±14 a	87.0±.82 a	74.2±1.23 a	27.2±1.17 a
	Control	270	3.64±.11 b	487±12 a	86.2±.70 a	70.1±1.05 b	24.5±0.98 ab
	Slow	434	3.39±.11 b	477±12 a	85.4±.73 a	67.7±1.10 b	22.0±1.04 b
Sex							
	Male	533	2.82±.08 a	478±8.0 a	84.0±.49 a	62.6±0.74 a	18.5±.68 a
	Female	591	4.62±.08 b	481±7.9 a	88.5±.78 b	78.8±0.73 b	30.6±.67 b
Hatch							
	One	778	4.05±.08 a	553±7.7 a	88.3±.47 a	73.3±0.70 a	27.8±.66 a
	Two	346	3.39±.08 b	436±8.1 b	84.1±.51 b	68.1±0.77 b	21.3±.70 b

[a,b]Means within main effects not followed by the same letter are significantly different ($P < .05$).

Table 7. Least-squares means and standard errors by line, sex and hatch for back score, body weight, and primary, secondary and tail length in second generation.

Main effects		No. obs.	Back score	Body weight (g)	Primary length (mm)	Secondary length (mm)	Tail length (mm)
Overall means		1745	3.46±.070	397.7±5.0	79.5±.76	60.5±1.04	18.10±.54
Line							
	Fast	621	4.28±.120 a	413.6±8.6 a	82.6±1.31 a	68.0±1.78 a	23.79±.93 a
	Control	576	3.40±.117 b	399.4±8.4 ab	80.3±1.27 a	60.2±1.73 b	17.49±.90 b
	Slow	548	2.70±.126 c	380.1±9.0 b	75.7±1.38 b	53.4±1.87 c	13.02±.98 c
Sex							
	Male	861	3.18±.076 a	418.1±5.3 a	79.1±.79 a	55.9±1.08 a	15.13±.58 a
	Female	884	3.74±.075 b	377.3±5.2 b	79.9±.78 b	65.1±1.07 b	21.07±.57 b
Hatch							
	One	1130	3.45±.073 a	396.6±5.1 a	78.6±.78 a	59.6±1.06 a	18.89±.56 a
	Two	615	3.47±.078 a	398.9±5.4 a	80.5±.80 b	61.5±1.09 b	17.31±.59 b

[a,b,c]Means within main effects not followed by the same letter are significantly different ($P < .05$).

respectively. In the first generation only the differences in back score, and secondary and tail length between the two divergent lines, fast and slow, were significant, while in the second generation the differences between all the measured traits were significant. Effectiveness of selection for better feathering was reported by Potemkowska et al. (1975) who was able to increase the proportion of better feathered birds from 20% male and 52% female to 64% male and 81% female in a Rhode Island Red stock of fowls after 12 years of selection.

However, it is worth noting that the significant difference between the body weight of the fast and slow lines in the second generation showed that there was positive response in weight gain when the birds had been selected for better feathering. This is in close agreement with the reports of some researchers who dealt with the slow and rapid feathering genes, k and K, such as Hurry and Nordskog (1953), Saeki and Katsuragi (1961), and Roy et al. (1980). However, a number of workers have reported no influence of early and late feathering on growth (Godfrey and Farnsworth, 1952; Sheridan and McDonald, 1963). The influence of rate of feathering on growth has not been satisfactorily explained. Some of the researchers who studied the effect of k and K genes on growth concluded that sex-linked feathering genotypes may share pleiotropic

associations with growth (Siegel et al., 1957a; Dunnington and Siegel, 1986). Some others concluded that the body weight difference between poor and better feathering chicks might be due to more energy being diverted from body growth functions to that of body temperature maintenance function in the poorly feathered genotypes (Somes and Weigh, 1980). Godfrey and Farnsworth (1952), nonetheless, were unable to demonstrate any relationship between the sex-linked early feather gene and growth to 10 weeks of age. They concluded that the action of the k gene took place in feather follicles and was not concerned with somatic growth in general. However, the chicks involved in this experiment were from the same genetical back-ground, slow feathering K gene, and the results show that better feathering birds had higher body weight (Table 7). Thus, it seems that it could be concluded that the difference between the two groups might be a result of physiological linkage (due to differences in thermoregulation ability) between faster feathering and rapid growth, as well as pleiotropic effects as a result of genetical linkage. There is no data in the results obtained in the present work which provide support for either cause.

Primary, secondary and tail length also started to show some differences due to the effect of divergent

selection in the first generation (Table 6). These differences became much more obvious in the second generation (Table 7). Warren (1938), McClary and Bearse (1941) and Jones and Hutt (1946) working with White Leghorn populations over a series of experiments, showed that a series of autosomal multiple alleles T, t^s, and t influence feathering. Chicks carrying the gene t^s, retarded, and t ,tardy, show a delay in the development of secondaries and tail length in the first few weeks of life. In this experiment, if it were assumed that in the basal population all of the T series alleles were available, it is possible to say that the effectiveness of divergent selection for feather growth could be due to the segregation of T alleles. This means that those birds carrying the T allele were selected as fast feathering birds. Those birds carrying t^s or t were selected as slow feathering birds. Furthermore, although the line when received was supposed to be homozygous for K, it is possible that the K^s and/or K^n emerged as a result of mutation and selected for in the slow line. It should be noted that at hatches when the primary and secondary feathers were examined phenotypic evidence of the presence of the fast feathering gene ,k, was observed. Chicks suspected of carrying the k gene were female and were low in number and were about 1 or 2 per 1000 total hatched.

Male chicks could have been heterozygous for the k

gene. However, there was no evidence that a Kk male was selected in either line as in the subsequent generation many more k females would have emerged.

However, it should be noted that in this experiment a huge amount of variation was observed for nearly all of the considered traits. This could lead us to believe that we were dealing with a series of genes rather than just a series of alleles. In order to confirm this possibility it seems further investigation is required over more generations, possibly crossing between selected groups and perhaps crossing with birds which have fixed genes affecting feathering.

3.2.2.2 Sex Effect

Sex was a significant source of variation for all of the considered traits in all of the generations except for body weight in the first generation (Tables 3 and 4). Growth and rate of feathering were better in the first generation than in the second generation. In both generations the females showed a superiority in feathering over the males. Thus dimorphism existed in all lines (Table 8). In first generation the difference between males and females in regard to feathering traits was quite obvious, but in the second generation the difference between males and females, especially in primary length, had diminished to the extent that the male of the fast line had longer primary than the

Table 8. Least-squares means by line * sex interaction for back score, body weight, and primary, secondary and tail length in base, first and second generation.

		Back Score		Body Weight (g)		Primary length (mm)		Secondary length (mm)		Tail length (mm)	
Generation	Line	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female
base		1.80	2.34	318	291	76.6	77.8	52.4	61.8	-	-
1	Fast	3.29	4.96	475	472	85.5	88.6	67.6	80.7	19.83	34.47
	Control	2.71	4.58	486	487	84.0	88.5	61.6	78.7	18.79	30.22
	Slow	2.46	4.32	471	481	82.5	88.3	58.5	76.9	16.92	27.17
2	Fast	4.08	4.47	436	390	83.3	81.9	65.1	70.9	19.73	27.87
	Control	3.11	3.70	418	380	79.9	80.6	55.4	65.0	14.74	20.24
	Slow	2.34	3.06	399	360	74.1	77.3	47.4	59.5	10.92	15.11

female. The overall difference was only 0.8 mm (Table 7). However, the difference still was significant at the .95 per cent level of probability. Overall, among considered feathering traits, it seems, tail length was the best indication of sex in both generations at 24 days of age.

The effect of sex in feathering with females being earlier feathered than males, in this study in agreement with Siegel et al. (1957a) who reported that female progeny feathered better than males in a two line divergent selection (superior and inferior) experiment.

Generally, the variation in feathering ability between males and females is credited either to a dosage effect of sex-linked genes or to some physiological differences between the two sexes.

Breneman (1941) reported considerable pituitary activity during the first few weeks of Rhode Island Red and White Leghorn chicks' life. This early pituitary activity results in gonadotrophin secretion which indirectly results in the production of a small amount of gonadal hormones, oestrogen and androgen. These hormones are produced due to stimulation of gonadal growth.

Females chicks have a greater amount of oestrogen than males (Sturkie, 1986). This was reported to be

responsible for better feathering in female than male-chicks by Siegel et al. (1957a).

The interesting points in Table 8 which should be noted are that the back score, and primary, secondary and tail length of the fast feathering males was greater than those of the slow feathering females for the second generation. These figures for feathering (Table 8) in generation two, reflect the effectiveness of selection over just a few generations.

3.2.2.3 Hatch Effect

Hatch accounted for a relatively large amount of variation in the first generation compared to the second generation (Tables 4 and 5). This might be mainly due to uncontrollable factors. However, the contribution of the hatch in the second generation was less than one per cent of the total variation within each trait (Table 5).

Overall, the contribution of different interactions on the total variation of each trait was less than one per cent in both generations, except for the sex-hatch interaction in the first generation, which was relatively high. This showed that males and females in the first generation had different reactions in the hatches. The differences in the hatches could be due to an unsettled external environment which affected internal environmental conditions. However, it seems

generally, females were more resistant to the fluctuation of the environment than males.

3.3 Heritability Estimates of Feathering and Body Weight

Heritability was estimated on the basis of full-sibs, and paternal and maternal half-sibs for the selected traits (back score, and primary, secondary and tail length) and the unselected trait, (body weight) for the first and second generations (Tables 9 and 10). The heritability estimates based on full-sibs were in the middle of the estimates for paternal and maternal half-sibs as was expected, because of the construction of the calculation formula. Heritability estimates based on the sire component of variance, h^2s, for feathering traits were quite variable between the first and second generations. They generally increased, in the second generation except for tail length, which was lower. As a rule, it is expected that as the population is being selected to produce the next generation, the amount of variation should decrease and as a result heritability should also decrease. However, the increase of heritabilities for the paternal half-sibs could be as a result of a new source of variation. This new source could be a reflection of the segregation of the genes which were an indirect response to the selection. However, considering this assumption, it seems that the series of tardy alleles, which are autosomal genes and

Table 9. Heritability estimates on the basis of full-sibs, paternal and maternal half-sibs and standard errors for back score, body weight, and primary, secondary and tail length in the first generation.

Traits	Full-sibs	Paternal half-sibs	Maternal half-sibs
Back score	.562±.072	.358±.109	.766±.122
Body weight	.839±.078	.776±.171	.903±.125
Primary length	.637±.075	.328±.103	.946±.126
Secondary length	.602±.074	.324±.103	.879±.124
Tail length	.599±.074	.625±.150	.574±.116

Table 10. Heritability estimates on the basis of full-sibs, paternal and maternal half-sibs and standard errors for back score, body weight, and primary, secondary and tail length in the second generation.

Traits	Full-sibs	Paternal half-sibs	Maternal half-sibs
Back Score	.458±.057	.435±.106	.480±.085
Body weight	.713±.066	.590±.131	.837±.098
Primary length	.873±.068	1.075±.189	.671±.093
Secondary length	.833±.068	1.024±.184	.643±.092
Tail length	.568±.062	.564±.127	.571±.089

have some control on slow feathering, could be suspected to be responsible for this increase in the variation, especially when the limited number of selected sires (only 16 birds per line) is noted.

The heritabilities based on maternal half-sibs showed a decline in the second generation compared to the first one (Tables 9 and 10). This decline was a normal selection response which was due to lower variation in the new generation of selected birds.

It would appear, from the heritabilities estimated by the full-sib method that the degree of feathering on the back, and primary, secondary and tail length were highly heritable (> .40). In the light of these findings, it can be suggested that individual selection should be effective in improving feathering traits.

From the literature reviewed, a number of reports dealing with heritability estimates of feathering were found. Heritability of feathering in eight-week old chickens was .51 according to Jaap and Morris (1937) and .34 according to Siegel (1963). Hurry and Nordskog (1953) reported a heritability of .42 and .33 for feathering in Barred Plymouth Rock and New Hampshire populations, respectively. An estimate of heritability for early feathering in a White Plymouth Rock population was .40 (Siegel et al., 1957a). However, the heritability estimates of back score in this study on

the basis of full-sib were .562 and .458 for the first and second generations, which is in fairly good agreement with those reported above. It should be noted that no reports were found in the literature of heritability of primary, secondary and tail length.

Heritability estimates for the non-selected trait, body weight, are presented in Tables 9 and 10 for the first and second generations, respectively. The estimates for the second generation were lower than the first one as was expected. The estimates for the second generation were .713±.066, .590±.131 and .837±.098 on the basis of full-sibs, and paternal and maternal half-sibs.

The relatively high heritability of body weight, according to this study, at 24/25 days of age indicated that mass selection for superior individuals would be effective in furthering improvement of this character.

Reports of heritability estimates of body weight in poultry are too numerous to compare with those found in the present study. Generally, the estimates found from the current study agree quite well with those reported in the literature, where the estimates run as low as .05 for early body weights, reported by Goodman and Jaap (1960), to as high as .88 for broiler chickens by Thomas et al. (1958).

3.4 Correlation Between Feathering and Body Weight

Genetic, phenotypic and environmental correlations among measurements taken at 24/25 days of age for the first and second generations are given in Tables 11 and 12, respectively. Genetic correlation estimates among feathering traits were positive and ranged from .305±.108 for primary length and back score to .864±.033 for secondary length and primary length in the first generation. In the second generation, genetic correlations were also positive and ranged from .422±.086 for primary length and back score to .890±.022 for secondary length and primary length. There were high genetic correlations between back score and tail length in both generations (.747±.058 and .733±.053 for the first and second generations, respectively) which shows that both traits could be easily substituted for each other whenever necessary. Also, there were reasonably high genetic correlations between body weight and back score, and body weight and tail length (.640±.071 and .556±.080 in the first, and .449±.085 and .605±.068 in the second generation) indicating that possibly genes affecting feathering also have an effect on body weight. However, there is a question whether this effect is a direct gene effect, such as pleiotropy, and/or an indirect effect, as, for example, when a better body weight is obtained as a result of the better feathered birds using less energy to keep warm. Therefore, no firm

Table 11. Genetic[a], phenotypic[b] and environmental[b] correlations on the basis of full-sib, analysis among the traits at about 24 days of age for the first generation

Trait	BS	BW	PL	SL	TL
Back score (BS)		.640±.071	.305±.108	.482±.092	.747±.058
Body weight (BW)	.509(.260)		.383±.095	.499±.086	.556±.080
Primary length (PL)	.375(.484)	.444(.681)		.864±.033	.401±.099
Secondary length (SL)	.524(.583)	.475(.476)	.766(.608)		.595±.078
Tail length (TL)	.617(.438)	.506(.441)	.414(.436)	.540(.457)	

[a]Genetic correlation ± approximate standard errors above the diagonal.

[b]Phenotypic correlations below the diagonal with environmental correlations in parentheses.

Table 12. Genetic[a], phenotypic[b] and environmental[b] correlations on the basis of full-sib, analysis among the traits at about 24 days of age for the second generation

Trait	BS	BW	PL	SL	TL
Back score (BS)		.449±.085	.422±.086	.596±.069	.733±.053
Body weight (BW)	.434(.450)		.274±.091	.376±.085	.605±.068
Primary length (PL)	.427(.612)	.343(.662)		.890±.022	.576±.070
Secondary length (SL)	.563(.650)	.358(.314)	.801(.288)		.736±.050
Tail length (TL)	.621(.510)	.437(.147)	.432(.117)	.562(.209)	

[a]Genetic correlation ± approximate standard errors above the diagonal.

[b]Phenotypic correlations below the diagonal with environmental correlations in parentheses.

conclusion can be reached regarding the direct and/or indirect effect of genes.

In the second generation, phenotypic correlations between back score and body weight, and, tail length and body weight were reasonably equal (.434 and .437, respectively) but the degree of environmental correlations of the two traits with body weight were different (.450 and .147, respectively). These environmental correlations showed that there was a lower environmental influence and non-additive genetic effect of body weight on tail length. In other words, the genetic link between tail length and body weight is stronger than that of back score and body weight (.605 vs. .449), as it is shown in Table 12. These results agree well with those reported by Hurry and Nordskog (1953). In this respect, the findings of this study were also consistent with earlier reports by Martin (1929), Schnetzler (1936), Jaap and Morris (1937) and Glazener and Jull (1946) who indicated that better feathering birds were heavier than poor feathering ones.

Overall, from the above results it could be concluded that selection for the simple and objective measurement of tail length is to be preferred over back score which is a simple but subjective estimate of feathering.

The use of tail length measurement as an indication of feathers offers a greater flexibility of age at which the measurement may be made. Whereas the back score estimate needs to be completed between 3 and 4 weeks, the tail measurement could be completed between 2 and 5 weeks, and possibly later. The use of both body and feather growth rate in a selection programme should produce a greater genetic gain in both traits than using body growth rate alone.

3.5 Broiler Production

From the selected birds of the base population and the selected birds of the first generation, two batches of broilers were produced to evaluate the amounts of progress of each line in the aforementioned generations. However, using the logic that the broilers from the later generation could be considered more representative of the latest progress in the selection programme, it was decided that the data of the broilers which were produced from the first generation be discussed here while the other broilers' data appear in Appendix VIII.

Least-squares means and standard errors for back score, body weight, and primary, secondary and tail length at 24 days of age are presented in Table 13. There were significant differences between the fast and slow lines for all the traits except body weight and the

Table 13. Least-squares means and standard errors by line and sex for back score, body weight, and primary, secondary and tail length at 24 days of age for a sample of broiler progeny of the first generation.

Main effects		No. obs.	Back score	Body weight (g)	Primary length (mm)	Secondary length (mm)	Tail length (mm)
Overall means		203	3.23±.07	637±5.6	84.2±.84	70.6±.77	26.8±.56
Line							
	Fast	63	3.69±.11 a	647±9.0 a	87.7±1.40 a	77.4±1.38 a	33.5±1.0 a
	Control	72	3.17±.11 b	619±8.5 b	86.7±1.32 a	72.6±1.29 b	26.0±.94 b
	Slow	68	2.82±.11 c	645±8.8 a	78.2±1.36 b	62.0±1.33 c	21.0±.97 c
Sex							
	Male	101	2.70±.09 a	674±7.4 a	82.5±1.13 a	65.2±1.09 a	20.6±.79 a
	Female	102	3.76±.09 b	601±7.4 b	85.9±1.13 b	76.0±1.09 b	33.0±.79 b

[a,b,c]Means within main effects not followed by the same letter are significantly different ($P < .05$).

fast feathering line was greater than the slow feathering one in all of these traits.

Body weights, feed intakes and feed conversions at 24, 35 and 49 days of age were not affected by line (Tables 14 and 15).

The data which were taken on starved weight, and plucked, carcass and abdominal-fat weights as a percentage of starved weight, showed that none of these traits were influenced by line (Table 16). But by adjusting abdominal-fat weight for starved weight, the difference between fast and slow lines became clear. The slow line produced lower abdominal-fat compared to the fast line. Lower storage of abdominal-fat, on the one hand, could be a result of the slow feathering birds producing more heat to keep their bodies warm compared to fast feathering ones which had better insulation at an earlier age, or, on the other hand, it could be as a result of slightly more efficient production of carcass weight. The data on percentage of carcass showed that slow line was slightly more efficient than the fast line (69.9 vs. 69.1). However, the difference between the lines was not significant. It seems for a definite conclusion, it may require more generations of selection to be practised.

Sex had a significant effect on all the measurements which were taken on the broilers at

Table 14. Least-squares means and standard errors by line and sex for body weight (BW), feed intake (FI) and feed conversion (FC) at first and second periods of the trial of the broiler progeny of the first generation.

Main effects		No. obs.$	24-day BW (g)	1-24 days FI (g)	1-24 days FC	35-day BW (g)	25-35 days FI (g)	25-35 days FC
Overall means		18	633±6	929±11	1.468±.012	1196±6	1160±9	2.066±.02
Line								
	Fast	6	645±11 a	938±18 a	1.456±.02 a	1218±11 a	1173±16 a	2.048±.04 a
	Control	6	624±11 a	928±18 a	1.488±.02 a	1174±11 a	1155±16 a	2.102±.04 a
	Slow	6	631±11 a	921±18 a	1.460±.02 a	1197±11 a	1154±16 a	2.047±.04 a
Sex								
	Male	9	665±9 a	973±15 a	1.463±.02 a	1284±9 a	1256±13 a	2.030±.03 a
	Female	9	602±9 b	885±15 b	1.473±.02 a	1108±9 b	1065±13 b	2.101±.03 a

$ Each observation is the average of a pen, containing approximately 50 birds.

a,b Means within main effects not followed by the same letter are significantly different ($P < .05$).

Table 15. Least-squares means and standard errors by line and sex for body weight (BW) at 49-day age, feed intake (FI), feed conversion (FC) at the third period, and cumulative feed intake (CFI), feed conversion of the whole trial Period (CFC), and 49-day weight as it adjusted for CFI of the broiler progeny of the first generation.

Main effects	No. obs.$	49-day BW (g)	36-49 days FI (g)	36-49 days FC (g)	1-49 days CFI (g)	1-49 days CFC	49-day BW adj. for CFI (g)
Overall means	18	1996±11	1736±13	2.187±.02	3826±21	1.921±.009	1996±9.1
Line							
Fast	6	2024±19 a	1751±20 a	2.192±.03 a	3861±37 a	1.912±.02 a	2012±16.4 a
Control	6	1978±19 a	1735±20 a	2.180±.03 a	3818±37 a	1.936±.02 a	1980±15.7 a
Slow	6	1987±19 a	1723±20 a	2.190±.03 a	3798±37 a	1.916±.02 a	1996±16.2 a
Sex							
Male	9	2180±16 a	1849±17 a	2.067±.03 a	4077±30 a	1.871±.01 a	2098±36.2 a
Female	9	1813±16 b	1624±17 b	2.308±.03 b	3574±30 b	1.972±.01 b	1894±36.2 b
Linear Regression Coeff.							.3233+1344*

$ Each observation is the average of a pen, containing approximately 50 birds.

a,b Means within main effects not followed by the same letter are significantly different ($P < .05$).

* Significant at $P < .05$.

Table 16. Least-squares means and standard errors by line and sex for starved weight, and plucked weight, carcass weight and fat weight on a percentage of starved weight, and fat weight as adjusted for starved weight of broiler progeny of the first generation.

Main effects		No. obs.	Starved weight(g)	% Plucked weight	% Carcass weight	% Abdo-fat weight	Adj. abdo-fat weight(g)
Overall means		178	2002±24.2	91.0±.08	69.3±.18	1.95±.06	38.5±1.26
Line							
	Fast	60	2016±30.6 a	91.0±.15 a	69.1±.32 a	1.99±.08 ab	39.5±1.68 a
	Control	59	1972±30.7 a	90.9±.15 a	68.9±.32 a	2.06±.08 a	40.4±1.69 a
	Slow	59	2016±30.8 a	90.9±.15 a	69.9±.32 a	1.80±.08 b	35.6±1.69 b
Sex							
	Male	88	2186±27.8 a	91.1±.12 a	69.5±.26 a	1.73±.07 a	34.9±1.71 a
	Female	90	1818±27.6 b	90.8±.12 b	69.1±.26 a	2.17±.07 b	42.1±1.70 b
Linear Regression Coeff.							.0155±.0045*

[a,b]Means within main effects not followed by the same letter are significantly different ($P < .05$).

* Significant at $P < .001$

different ages, except for feed conversion at 1-24 and 25-35 days of age and the percentage of carcass weight (Tables 13, 14, 15 and 16). Males had a higher body weight while females had a higher back score and feather length.

The effect of sex on feathering in different parental generations was discussed earlier, and here, broiler production, reasonably the same results were obtained. However, these results confirmed the effect of sex in the earlier results.

Sexual dimorphism in body weight is well known to occur soon after hatching, and this was quite evident for body weight at 24 days of age (Table 14). Considering 35-day and 49-day body weight, males had higher body weight than females. By adjusting 49-day body weight for cumulative feed intake in the experimental period, males had higher body weight than females (2098 vs. 1894 g) which showed males were more efficient than females at converting consumed feed to body gain. No significant ($P < .05$) interaction occurred between line and sex for any measured trait, indicating that the effect of sex was reasonably constant and predictable. Lowe and Merkley (1986) reported that the effect of sex on gain, feed conversion and body weight was in favour of males while there was significant superiority of females in back feather score. Their

results were completely in agreement with the results obtained in this experiment.

Table 16 shows that there was a significant difference between males and females in starved weight which might have been due to the higher 49-day weight of the males. Males produced a higher percentage of plucked weight than females which showed males were more efficient. The higher efficiency of the males was also observed in the percentage of carcass production but this difference was not statistically significant.

A comparison between males and females showed that females produced more fat than males on the basis of equal starved weight (Table 16). The higher fat deposition in females could be simply a sex effect and/or a specific gene effect. Edwards et al. (1973) and Fisher (1984) reported, a higher percentage of total body-fat and abdominal-fat in females compared to that of males. Also, Leenstra (1982) found that in female chicks from 3 weeks to 10 weeks, the total percentage of fat increased by 9 per cent while in the same period, males increased by only 3 per cent. Recently, Leenstra and Pit (1987) working with different lines of broilers, claimed that the difference between fat deposition in males and females in the lean lines, could be caused by a major gene located on the sex chromosome. They also claimed that in some other lines the difference between the high fat and the low fat line might be due to a

normal autosomal gene which influences the amount of abdominal-fat deposition. However, there is general agreement between the findings of Edwards et al. (1973), Fisher (1984) and Leenstra (1962) and the results obtained in this study.

Within line and sex, the results in Table 16 also showed that there was a strong relationship between starved weight and abdominal-fat weight. This means, for a unit increase in body weight, abdominal-fat would increase by .0155 of a unit. In other words, under ad libitum feeding as in this experiment, the birds with a large appetite were capable of over-eating to such an extent that feed intake exceeded the birds maximum capacity for lean tissue growth and thus started to store extra fat (Summers and Leeson, 1979).

3.6 Broiler Production at Different Temperatures

3.6.1 Measurements at 24 Days of Age

Least-square means by line, sex and temperature for back score, body weight, and primary, secondary and tail length, and also back score and tail length which were adjusted for body weight at 24 days of age, are shown in Table 17. The difference between fast and slow feathering groups for these measurements was significant. In other words, there were two distinct feathering groups of chicks involved in this experiment.

Table 17. Least-squares means and standard errors by line, sex and temperature for back score, body weight, and primary, secondary and tail length, and back score and tail length which were adjusted for body weight at 24 days of age.

Main effects		No. obs.	Back score	Body weight (g)	Primary length (mm)	Secondary length (mm)	Tail length (mm)	Back score adj. for BW	Tail length adj. for BW (mm)
Overall means		371	4.67±.05	766.3±4.1	94.9±.4	81.9±.7	37.1±.5	4.67±.04	37.1±.5
Line									
	Fast	125	5.14±.08 a	801.2±7.0 a	96.6±.6 a	88.5±1.1 a	44.9±.9 a	5.06±.08 a	43.4±.9 a
	Control	124	4.70±.08 b	746.1±7.0 b	95.4±.6 a	83.1±1.1 b	35.5±.9 b	4.75±.08 b	36.3±.9 b
	Slow	122	4.16±.08 c	751.1±7.1 b	92.6±.6 b	73.9±1.2 c	30.9±.9 c	4.19±.08 c	31.5±.9 c
Sex									
	Male	185	4.20±.07 a	811.9±5.8 a	94.9±.5 a	78.7±.93 a	29.2±.8 a	4.07±.07 a	27.3±.8 a
	Female	186	5.15±.06 b	721.0±5.7 b	94.9±.5 a	85.1±.93 b	45.0±.8 b	5.27±.07 b	46.9±.8 b
Temperature									
	30°C	185	4.53±.07 a	746.0±5.8 a	93.9±.5 a	80.1±.93 a	36.7±.8 a	4.58±.07 a	37.5±.7 a
	20°C	186	4.81±.06 b	786.5±5.7 b	95.8±.5 b	83.7±.93 b	37.6±.8 a	4.76±.07 b	36.7±.7 a
Linear Regression Coeff.								.0024+.0006*	.0413+.006*

a,b,c Means within main effects not followed by the same letter are significantly different ($P < .05$).

* Significant at $P < .0001$.

The sex effect was a significant source of variation for the aforementioned traits except for primary length.

Temperature had a significant effect on the measurements taken at 24 days of age, except for tail length. In a further analysis, back score and tail length were adjusted for body weight. The results showed that apart from body weight, back score could be considered as an indication of back feather cover within different temperatures, while tail length could be considered as a measurement independent of temperature effects. It is known that the activity of the thyroid is inversely related to environmental temperature (Cogburn and Harrison, 1980). The rate of feathering and feather structure of poultry is controlled in part by the thyroid hormones (Spearman, 1971). The present results indicate that the slower rate of feathering on the back at the higher temperature is independent of somatic growth rate. This implies that there are separate genes involved in feather growth and somatic growth and that the thyroid hormones have different effects on each. However, since tail feather growth was not affected independently by temperature it may be concluded that a different set of hormones control their growth. There is a possibility that these are the sex hormones (Somes, 1975). The phenomenon of the luxurious growth of the male tail feathers is one of the classical examples of

the secondary sexual characteristic of the males. This implies that there is a set of genes which control tail feathers growth and that they respond to testosterone production.

Also, it was observed that within the main factors (line, sex and temperature), there is a significant relationship between back score and tail length with body weight at 24 days of age (Table 17). This means, overall, that those birds who had a higher back score and/or longer tail length also had a higher body weight. Adjusted regression coefficients in Table 17 shows that by increasing each .024 unit of back score and/or each .413 mm of tail length, body weight at 24 days of age would improve by 10 g. It seems that due to the strong genetic correlation (.73) between back score and tail length (Table 12), either of these traits could have a significant influence on body weight.

The amount of depression of back score by temperature effects are summarised in Table 18. Generally males were more depressed than females (7.1% vs. 5.3%). Among the males of different lines the slow groups were the most affected (14.3%) while the fast line was the least affected (1.9%). However, there were variable amounts of depression among females of the different lines. These results showed that as regards feathering, fast feathering broilers can do better than slow feathering ones in normal and high environmental

Table 18. Means and average standard errors of back scores, and the percentage of depression by temperature effects.

Temperature Sex

	Sex	
Temperature	Male	Female
30°C	4.033±.093	5.011±.093
	(% 7.1)[a]	(% 5.3)
20°C	4.340±.093	5.293±.093

Temperature Line Sex

	Line		
	Fast	Control	Slow
Male			
30°C	4.567±.16	4.129±.16	3.400±.16
	(% 1.9)	(% 5.9)	(%14.3)
20°C	4.656±.16	4.387±.16	3.968±.16
Female			
30°C	5.484±.16	5.063±.16	4.484±.16
	(% 6.2)	(% 3.2)	(% 5.9)
20°C	5.844±.16	5.233±.16	4.767±.16

[a] Percentage of depression in parenthesis

temperatures. In other words, comparing slow feathering and fast feather birds, it seems fast feathering ones are more suitable for subtropical and tropical countries.

These results confirm the early report of Radi and Warren (1938). They showed a depression of feather growth under the high temperature regime when comparing 20°C and 30°C. They concluded that low temperature had a stimulating influence on feather growth. The influence of temperature was more evident in the females. The rate of improvement in feathering was 28.5 per cent for females while it was only 19 per cent for males.

3.6.2 Feed Consumption and Conversion

Body weight, feed intake and feed conversion at 24 days, and five and seven weeks of age were not significantly affected by line (Tables 19 and 20). However, on looking more closely at the data, it may be seen that the growth rate for the fast line was slightly higher than for the slow line but feed conversion was slightly less efficient for the fast line. By adjusting 49-day body weight for cumulative feed intake over the whole period, it is shown (Table 20) that the slow line gained 1.2 per cent more than the fast line (1914.8 vs. 1891.4 g). However, this result showed that, although

Table 19. Least-squares means and standard errors by line, sex and temperature for body weight (BW), feed intake (FI) and feed conversion (FC) at first and second periods of the trial.

Main effects	No. obs.$	24-day BW (g)	1-24 days FI (g)	1-24 days FC	35-day BW (g)	25-35 days FI (g)	25-35 days FC
Overall means	24	764±6	1191±9	1.559±.007	1287±10	1090±10	2.102±.03
Line							
Fast	8	783±10 a	1221±15 a	1.560±.01 a	1312±18 a	1099±17 a	2.094±.04 a
Control	8	746±10 b	1172±15 b	1.572±.01 a	1271±18 a	1092±17 a	2.106±.04 a
Slow	8	762±10 ab	1178±15 ab	1.544±.01 a	1278±18 a	1079±17 a	2.106±.04 a
Sex							
Male	12	807±8 a	1262±12 a	1.563±.01 a	1386±15 a	1184±14 a	2.066±.04 a
Female	12	720±8 b	1119±12 b	1.554±.01 a	1188±15 b	996±14 b	2.138±.04 b
Temperature							
30°C	12	751±8 a	1137±12 a	1.513±.01 a	1211±15 a	1009±14 a	2.201±.04 a
20°C	12	776±8 b	1245±12 b	1.605±.01 b	1363±15 b	1172±14 b	2.002±.04 b

$ Each observation is the average of a pen, containing approximately 33 birds.

a,b Means within main effects not followed by the same letter are significantly different ($P < .05$).

Table 20. Least-squares means and standard errors by line, sex and temperature for body weight (BW), feed intake (FI), feed conversion (FC) at the third period, and cumulative feed intake (CFI) and feed conversion of the whole trial Period (CFC), and 49-day body weight as it adjusted for cumulative feed intake.

Main effects	No. obs.$	49-day BW (g)	36-49 days FI (g)	36-49 days FC (g)	1-49 days CFI (g)	1-49 days CFC	49-day BW adj. for CFI (g)
Overall means	24	1901±20	1689±33	2.868±.06	3969±45	2.097±.012	1901±9.9
Line							
Fast	8	1928±34 a	1746±57 a	2.989±.10 a	4067±78 a	2.124±.02 a	1891±18.3 a
Control	8	1900±34 a	1715±57 a	2.825±.10 a	3980±78 a	2.101±.02 a	1896±17.3 a
Slow	8	1873±34 a	1604±57 a	2.791±.10 a	3862±78 a	2.066±.02 a	1914±18.5 a
Sex							
Male	12	2057±28 a	1835±47 a	2.904±.08 a	4281±64 a	2.096±.02 a	1938±23.8 a
Female	12	1744±28 b	1542±47 b	2.832±.08 a	3658±64 b	2.098±.02 a	1863±23.8 b
Temperature							
30°C	12	1658±28 a	1433±47 a	3.223±.08 a	3578±64 a	2.155±.02 a	1808±27.9 a
20°C	12	2143±28 b	1944±47 b	2.513±.08 b	4361±64 b	2.040±.02 b	1993±27.9 b
Linear Regression Coeff.							.3829+1344*

$ Each observation is the average of a pen, containing approximately 33 birds.

a,b Means within main effects not followed by the same letter are significantly different ($P < .05$).

* Significant at $P < .0001$.

the fast and slow feathering lines were significantly different as regards feathering at 24 days of age (Table 17) still there was not any sign of a significant effect of feathering on broiler production traits which were not included as selection parameters in the selection programme. It follows therefore that more generations of selection would be required before reaching a definite conclusion for the effect of feathering on broiler production traits in these populations.

Finally, it should be noted that non-significant differences between fast and slow feathering lines for growth and feed conversion which were obtained in this experiment confirmed the results obtained from the broilers produced from the selected parents of the first generation.

Sex was a significant source of variation for feed intake and consequently for body weight at different periods, but its effect on feed conversion did not show any significance in any period. However, by adjusting 49-day body weight for cumulative feed intake (Table 20) males had grown more efficiently than females (1938.6 vs. 1863.4) by 4.04 per cent.

Body weight, feed intake and feed conversion at 24 days, and five and seven weeks of age were significantly

affected by the different regimes of temperature (Tables 19 and 20). The birds kept under the low temperature regime had higher body weight and also they consumed more feed compared to those kept under the high temperature regime. By comparing the feed conversion of the two groups, it was obvious that at 24 days of age the high temperature regime birds had slightly lower feed conversion (1.5126 vs. 1.6051), but by five and seven weeks of age this changed in favour of the low temperature regime birds (2.201 vs. 2.002 in 25-35 days and 3.223 vs. 2.513 in 36-49 days of age). So, between 24 and 35 days of age there is a point at which the birds will start to express a negative response to high temperature. From that time, the chicks in the high temperature, for the same amount of feed will start to gain less than those in the normal temperature (Table 20). This result became clearer when 49-day body weight was adjusted for cumulative feed intake over the whole period. This means, for the same amount of feed consumed, the high temperature regime birds produced 1808 g body weight while the other group produced 1993 g body weight, or, 10.2 % higher than the first one. A decrease in efficiency may be explained in terms of changes in the relative amount of energy expended on gain and maintenance; a decrease in efficiency will occur if less energy is used for gain relative to that used for maintenance. McCarthy and Siegel (1983) explained several methods of altering feed efficiency.

One of the ways which may be useful to explain the results obtained in this experiment is that a decrease in efficiency might arise as a result of a proportionate increase in the cost of maintenance per unit of body weight. This kind of increase could result from increases in different aspects of maintenance, such as thermoregulatory energy requirement. If the difference in temperature caused an increased thermoregulatory cost per unit of weight, it could result in an increase in maintenance energy cost. Daghir (1987) pointed out that birds in a high temperature need a higher proportion of consumed energy for maintanence purposes compared to those kept under normal temperature. He concluded that this extra energy would be used to dissipate by respiratory thermoregulation the extra heat burden inside the body. Thus the proportion of intake energy used for maintenance increases and the net energy decreases. This means, the overall growth of the bird would be affected, depression would appear and feed efficiency will decrease under a high temperature. Since the energy requirements are less a higher protein content in the diet could improve growth rate.

Both sexes were negatively affected by high temperature. The effect, however, appeared to be greater for the males than females (Table 21). The reduction in weight gain in a high temperature regime could be a

Table 21. Means and average standard errors of 49-day body weight and percentage of depression by high temperature.

Temperature Sex*

	Sex	
Temperature	Male	Female
30°C	1744±40.9	1572±40.9
	(% 26.4)[a]	(% 17.9)
20°C	2371±40.9	1916±40.9

Temperature Line Sex

	Line		
	Fast	Control	Slow
Male			
30°C	1785±70.8	1754±70.8	1694±70.8
	(% 26.9)	(% 24.7)	(% 27.6)
20°C	2443±70.8	2331±70.8	2339±70.8
Female			
30°C	1566±70.8	1590±70.8	1562±70.8
	(% 18.4)	(% 17.5)	(% 17.8)
20°C	1920±70.8	1927±70.8	1899±70.8

[a]Percentage of depression in parenthesis.

*Significant at $P < .01$.

primary response to temperature and/or a consequence of loss of appetite. Hurwitz et al. (1980) found that feed intake and body weight gain decreased linearly as ambient temperatures increased. At ambient temperatures above 28°C even feed efficiency decreased, especially in the males. The same was found by Meltzer (1984) in a commercial flock of broilers. He calculated the heat effect on feed efficiency on the basis of hourly accumulated heat load.

It is generally accepted that broilers adapt daily feed intake to changes in dietary energy concentration so as to maintain a constant intake of metabolizable energy. However, the precision of this adaption varies, and is influenced by age, strain, diet composition, ambient temperature and probably other factors.

However, by further analysis of the 49-day body weight adjusted for cumulative feed intake (Table 22) the body weight of males was found to be much more affected than females (14.1% vs. 4.1%) under the high temperature regime, while females were more efficient than males under such conditions. In contrast, under a normal temperature regime, males were more efficient than females (2085.0 vs. 1901.9 g). If these depressions are considered as an effect of factors other than feed intake on 49-day body weight, by adjusting 49-day body weight for feed intake, it could be concluded that

Table 22. Means and average standard errors of 49-day body weight adjusted for feed intake, and percentage of depression by high temperature.

Temperature Sex*

	Sex	
Temperature	Male	Female
30°C	1792±42.1	1824±42.1
	(% 14.1)[a]	(% 4.1)
20°C	2086±42.1	1902±42.1

Temperature Line Sex

	Line		
	Fast	Control	Slow
Male			
30°C	1763±49.1	1818±49.1	1795±49.1
	(% 16.6)	(% 11.9)	(% 13.7)
20°C	2114±49.1	2064±49.1	2079±49.1
Female			
30°C	1783±49.1	1822±49.1	1868±49.1
	(% 6.5)	(% 3.3)	(% 2.5)
20°C	1906±49.1	1883±49.1	1916±49.1

[a]Percentage of depression in parenthesis.

*Significant at P < .01.

females were more resistant than males under a high temperature regime. However, the higher resistance of females under the high temperature could be simply as a result of sex effect and/or it could be due to the other factors such as better feather cover, higher general activity or lower female body weight. Dale and Fuller (1980) showed that factors other than feed intake are responsible for the adverse effect of heat stress. They compared the chicks in a cool and warm environment and reported that 37 per cent of growth depression is due to these factors. Van Kampen (1977) also found that activity may play a role in the bird's response to heat, since lower critical temperature can be reduced by as much as $5^{o}C$ if birds are made active.

However, it seems that to determine the percentage of involvement of any factor other than feed intake in heat resistance, further research is required.

3.6.3 Starved Weight and Carcass Compositions

Least-squares means of starved weight, and plucked, carcass and abdominal-fat as a percentage of starved weight and adjusted abdominal-fat weight for starved weight, by line, sex and temperature effects are shown in Table 23. Line was a significant source of variation for the traits except for percentage of carcass. A comparison between fast and slow lines showed

Table 23. Least-squares means and standard errors by line and sex and temperature for starved weight, and plucked weight, carcass weight and fat weight as a percentage of starved weight, and fat weight as it adjusted for starved weight of broiler progeny of the first generation.

Main effects	No. obs.	Starved weight(g)	% Plucked weight	% Carcass weight	% Abdo-fat weight	Adj. abdo-fat weight(g)
Overall means	158	1896±13.9	88.97±.059	67.81±.173	2.0879±.058	39.00±1.10
Line						
Fast	56	1978±23.3 a	89.17±.160 a	67.96±.209 a	2.3613±.098 a	43.93±1.93 a
Control	51	1893±24.5 b	88.65±.168 b	67.40±.304 a	1.9120±.103 b	35.88±1.94 b
Slow	51	1816±24.5 c	89.08±.168 ab	68.05±.304 a	1.9904±.103 b	37.19±2.00 b
Sex						
Male	74	2083±20.3 a	89.19±.139 a	68.06±.252 a	1.8292±.085 a	34.09±2.02 a
Female	84	1709±19.0 b	88.75±.131 b	67.55±.237 a	2.3466±.080 b	43.91±1.93 b
Temperature						
30°C	76	1687±20.0 a	89.17±.138 a	68.53±.249 a	2.1730±.084 a	40.87±2.09 a
20°C	82	2105±19.3 b	88.77±.132 b	67.08±.240 b	2.0027±.081 a	37.13±2.05 a
Linear Regression Coeff.						.02038±.0065*

a,b,cMeans within main effects not followed by the same letter are significantly different ($P < .05$).

* Significant at $P < .001$

only starved weight, percentage of abdominal-fat weight and adjusted abdominal-fat weight were significant. The fast line had a significantly higher starved and percentage of abdominal-fat weight than the slow line. The reason for the higher fast line' starved weight is the higher 49-day body weight of that line (Table 20).

All considered traits except percentage of carcass weight were significantly affected by sex. However, males had significantly higher starved and plucked weight while females had a higher percentage of abdominal-fat weight. One of the possibilities that can explain higher growth rate in males and higher percentage of abdominal-fat in females could be the energy cost of growth increments. The energy cost of the growth increments in female chicks is greater than that in male chicks (Sturkie, 1986). This could be as a result of a greater ability of the female to fatten during growth, because the energy content of the gained body weight varies directly with the fat content of the increase body weight. However, it should be noted that according to Sturkie (1986) this difference between the male and the female fowl in this respect is largely due to male hormones and could be abolished if the males were caponised. The administration of testosterone propionate could increase females' growth rate to equal that of males (Sturkie,1986).

The higher percentage of abdominal-fat weight in females is in agreement with the results of Fisher (1984) and Edwards et al. (1973) who reported that in females the increase in percentage of total body fat and abdominal fat greatly exceeds that of males. Ehinger and Seemann (1982) found in commercial broilers slaughtered between 35 and 53 days of age, a clear effect of sex on the percentage of fat. Males had on average a total of 12% fat, while females had 14.4%. The data in this experiment showed (Table 23) males with 1.83 per cent, had 28.3 per cent less abdominal-fat than females which had 2.35 per cent abdominal-fat. Hakansson et al. (1978b) have demonstrated that in females the amount of abdominal-fat is a larger part of the total body fat than in males. Thus it could be concluded that the actual difference between males and females in percentage of body fat is less than the 28.3 per cent which was found in this experiment, as a difference in the percentage of abdominal-fat weight between males and females.

In the preliminary analysis it was found that the high temperature had a negative effect on starved weight which was due to the lower 49-day body weight, but had a positive effect on percentage of plucked and carcass weight (Table 23). However, there was no significant effect of high temperature on the percentage of

abdominal-fat or on the adjusted fat weight, which is in agreement with the results of Hurwitz et al. (1980). They concluded that the lack of temperature effect on body fat indicates that feed was consumed according to the needs of any given temperature.

Yet, further more detailed analysis showed that there was large difference between males under high temperature and those kept under normal temperature for the percentage of abdominal-fat weight (21.9%) while there was only 0.5 per cent difference between females kept under high and normal temperatures (Table 24).

The maintenance energy requirement of male and female broilers decreases as temperature increases up to around 27^{o}C (dry bulb) (Daghir, 1987; Hurwitz et al., 1980) above which temperature the maintenance requirement increases again. Since the energy intake of males and females decreases linearly as temperature increases the productive energy for growth will depend on the relative changes in energy intake and maintenance requirements. The difference between the growth and body composition of males and females at different temperatures reflect the selective changes and absolute levels of heat production, maintenance requirement and energy intake.

The difference in growth and body composition between males and females in the present experiment,

Table 24. Means and average standard errors of fat weight as a percentage of starved weight and percentage of extra storages of fat due to high temperature.

Temperature Sex

	Sex	
Temperature	Male	Female
30°C	2.018±.117	2.365±.117
	(% 21.9)[a]	(% 0.5)
20°C	1.655±.117	2.352±.117

Temperature Line Sex

	Line		
	Fast	Control	Slow
Male			
30°C	2.232±.204	1.942±.204	1.849±.204
	(% 17.4)	(% 22.4)	(% 25.4)
20°C	1.901±.204	1.586±.204	1.474±.204
Female			
30°C	2.711±.204	2.075±.204	2.232±.204
	(% 4.2)	(% 1.4)	(% -7.4)
20°C	2.601±.204	2.047±.204	2.411±.204

[a] Percentage of depression in parenthesis

where the two temperatures used, 20°C and 30°C, do not necessarily provide the same levels of thermal comfort for both sexes, are caused by the interaction between the energy metabolism factors mentioned above and the composition of the diet.

Another factor which influences the dichotomic reaction of males and females may be the different rates of feather growth. The faster feathering females will have a lower thermoregulation temperature requirement and when consuming the same diet as males, should have a higher quantity of energy which is surplus to the requirements for lean growth.

The same concept should apply between feather growth rate selection lines within sex. The faster feathering lines, on the basis of the above argument, should have a higher carcass fat content than the slower feathering lines (Table 24). The data obtained from the males fits this concept quite well, while that of the females does not, which suggests that there are other factors to take into account.

The protein:energy ratio of the diet is another important factor determining carcass fat. The diet used in the present experiment may have been responsible for the observed differences between males and females. In order to obtain a constant carcass fat content the

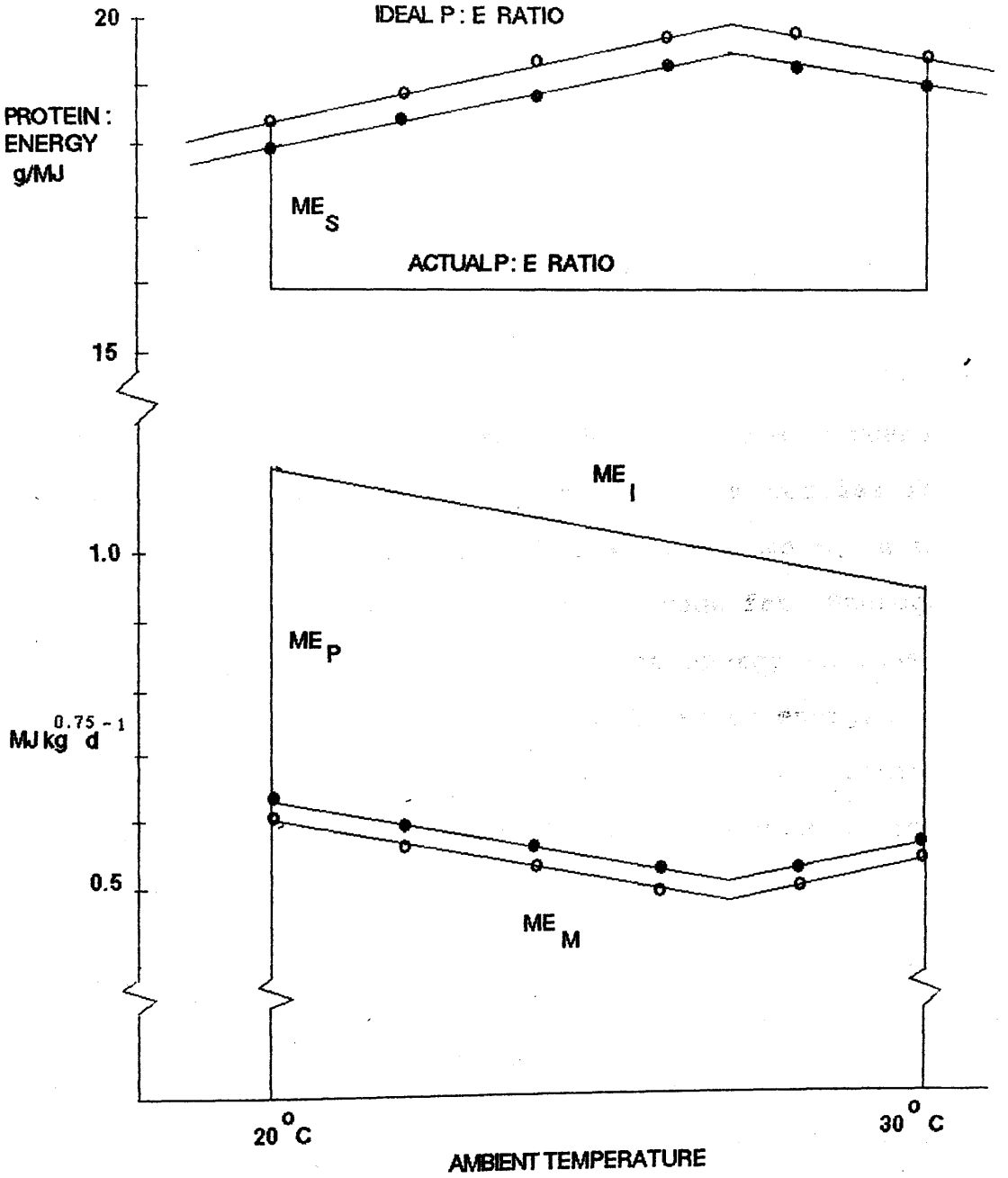
protein:energy ratio would need to change according to sex, rearing temperature, and feathering coverage.

The integration of the many factors discussed above is summarised and illustrated below.

3.6.4 "A scheme of the relationship between environmental temperature, metabolizable energy intake, maintenance energy requirement, productive energy, rate of feathering and protein:energy ratio of the diet."

The scheme which is illustrated in Figure 6 was constructed using actual body weight and feed intake data obtained in the experiment and an assumed dietary metabolizable energy content of 12.5 MJ/kg. The energy content of gain was calculated by assuming daily gains in lean and fat in the carcass of 51 and 28, and, 4 and 3 g, at 20°C and 30°C, respectively for broilers between 36 and 49 days of age. The estimates of the gains were made from the data of Hakansson et al. (1978a) assuming the above dietary energy content. The energy content of the gain was calculated assuming an energy content of lean and fat of 6 and 39 MJ/kg, respectively. The heat increments for protein and fat synthesis were assumed to be 29 and 14 MJ/kg, respectively.

Figure 6. A scheme of the relationship between environmental temperature, metabolizable energy intake(ME_I), maintenance energy requirement(ME_M), productive energy(ME_P), rate of feathering and protein:energy (P : E) ratio of the diet.



● SLOW
o FAST
ME_S = Surplus energy used for synthesis of storage fat (for detail see text).

Thus the partition of energy intake in the scheme was constructed as:

$$ME_I = ME_M + (ME_C + HI)_{Lean} + (ME_C + HI)_{Fat}$$

Where

ME_I = metabolizable energy intake

ME_M = metabolizable energy used for maintenance

ME_C = metabolizable energy content of lean and fat

HI = heat increment of synthesis of lean and fat.

The protein:energy ratio was approximated using the information giving by Hurwitz *et al.* (1980) and ratio is assumed to be ideal in the sense that the broiler is able to grow with a minimum carcass fat content at any temperature. The minimum carcass fat is regarded as non-storage fat whereas more than the minimum quantity is regarded as storage fat. Storage fat can be used as a reserve source of energy whereas non-storage fat cannot be used normally as an energy source. If the bird is fed a diet which has a protein:energy ratio other than ideal it would deposit greater quantities of fat.

If a broiler consumes a feed which has a protein:energy ratio greater than the ideal the quantity of fat deposited will be less per unit of energy in the diet than if the protein:energy ratio was less than the

ideal. It should be noted that in the former curves, protein would be catabolised which would yield less energy that can be synthesised into fat.

Finally the differences between broilers having different rates of feathering are taken into account. The maintenance energy requirement of the fast feathering line was assumed to be 5 per cent less than that of the slow feathering line because the fast line had a 5 per cent higher body weight at the end of the experiment. When broilers of both lines are given the same diet the scheme accounts for the higher quantity of storage fat in the fast line at temperatures between 20°C and 30°C.

It should be noted that the data obtained from males fitted the above scheme well, but those of the females did not. Modifications to the general scheme would be needed to account for the female.

3.7 Conclusion

From the data of: two generations of selection for feathering and of the associated trait, body weight in a population of slow feathering grand parent chickens; two batches of broilers produced from base and generation one; and a batch of broiler produced under different temperatures, results were obtained which clearly demonstrate the following:-

1. Based on the method of full-sib correlations, heritabilities of back score and tail length were found to be .562±.072 and .599±.074 in the first generation while they were .458±.057 and .568±.062 in the second generation, respectively.

Due to the high estimates of heritabilities of feathering traits (> .40), some of the genetic variations are of the additive type. This would suggest that individual selection at an early age, 24/25 days of age, would be effective in improving the feathering in slow feathering chicken populations.

2. In both generations, there were strong genetic correlations between back score and tail length (.747±.058 and .733±.053), showing that they can be a good substitution for each other. Since tail length is a much more objective measurement than back score, it could be suggested that as a single measurement for

selection, tail length should be preferred.

3. The responses of back score to plus and minus selection resulted in back score differences in female progeny between the two selected lines of .64 and 1.41 with the rapid feathering birds being superior, for the first and second generations, respectively. On the other hand, these differences in the male progeny were found to be .83 and 1.74 for the two aforementioned generations, respectively.

4. The heritability of 24-day body weight as estimated from full-sib analysis was found to be .839±.078 in the first and .713±.066 in the second generation of selection. Considering these estimates, phenotypic selection for body weight at 24 days of age should be effective in promoting genetic improvement of this character in a slow feathering chicken population.

5. Estimation of the phenotypic correlations between back score and 24-day body weight, and tail length and 24-day body weight obtained from variance and covariance analysis were positive in both generations. The genetic correlations, as estimated from sire plus dam variance components, between 24-day body weight and back score, and 24-day body weight and tail length were .640±.071 and .556±.080, respectively, in the first generation. In the second generation, these genetic correlations were .449±.085 and .605±.068 for the

respective aforementioned traits. These figures for the phenotypic and genetic correlations between feathering traits, back score and tail length, and 24-day body weight furnish good evidence that selection for chicks exhibiting rapid feathering development would automatically improve body weight at 24-days of age and vice versa.

6. There was an asymmetric response in back score and tail length. The fast feathering line gained more, while the slow feathering line lost less compared to the control line. On average, males and females of the fast feathering line gained +.86 and .65 unit of back score; +4.2 and +7.25 mm of tail length and +18.4 and +10.0 g of body weight while the respective figures for males and females of the slow line were -.42 and -.43 unit of back score; -2.2 and -3.9 mm of tail length; and -13.7 and 10.2 g of body weight, compared to the control line.

7. Overall, there was not any significant difference between the selected lines as regards feed conversion and body weights in broilers produced from the base and first generations. Male chicks produced more efficient and higher body weight compared to female ones.

8. Raising a batch of broilers under hot ($30^{o}C$) and normal ($20^{o}C$) temperatures showed that a hot temperature can significantly depress growth rate and

feather growth, excluding tail length. It also will increase feed conversion ratio. However, the exception was feed conversion up to 24 days of age. Females were found to be more resistant than males to a high temperature compared to a normal one.

9. There was a positive relationship between starved weight and the amount of abdominal-fat weight, so the birds which were heavier generally stored a higher percentage of abdominal-fat.

APPENDIX I

Feather Structure and Function

Considering the plumage of the adult fowl, three types of feather can be recognised which vary both in structure and function. The largest of these are called the contour feathers which form the outermost protective covering. According to Spearman (1971) the evolution of specialised contour feathers over the wing (remiges) and over the tail (retrices) was primarily for flight. However, they are less well developed in the domestic fowl than in the other species. Bradley (1972) structurally explained contour feathers as a shaft or rachis on to which two series of paralleled barbs, collectively termed the vane, are attached. From each barb spring two rows of barbules, the barbules interlocking with proximal barbules of the adjacent row.

The second type of feathers are called the down feathers, or plumules, which are most prominent in the chick. The differences between plumules and contour feathers are that the plumules have a shorter rachis, with no interlocking of barbules, and function as an insulating layer (Spearman, 1971).

The final feather type, filoplumes, are small hairlike structures with barbs confined to the apex (Landsborough-Thompson, 1964). Their exact function is

not clearly understood but Lucas and Stettenheim (1972) reported that it seems, they are part of the system that provides sensory input for the position of the larger feathers.

According to Spearman (1971) the initial coat of feathers formed during development of the embryo closely resembles the down feathers of the adult fowl. A second generation of feathers appear a few days after hatch. However, a series of subsequent moults occurs until eventually a definitive adult plumage replaces all juvenile feathers (Deschutter and Leeson, 1986).

Finally, the mechanism of the moult cycle was explained by Watson (1963) who reported that the shedding of old feathers is initiated by growth of new feathers which actively push the old feathers from the follicles.

APPENDIX II

Vaccination Programme For
Replacement Stocks

Age	Vaccine	Administration
Day-old	Marek's	Intramuscular (IM) Injection
14 days	Newcastle (Hitchner B1)	Coarse Spray
18-21 days	Infectious Bronchitis (IB) (H 120)	Coarse Spray
4 weeks	Marek's	IM Injection
6 weeks	Newcastle (Hitchner B1) + IB (H 120)	Drinking Water
8 weeks	Gumboro (IBD)	Drinking Water
12 weeks	Avian Encephalomyelitis	Drinking Water
16/18 weeks	Ultravac (IB+Newcastle+ IBD)	IM Injection

APPENDIX III

Temperature Schedule For Replacements and Broiler Stocks

Age	Temperature °C		
Days	Minimum	Optimum	Maximum
1	31.0	32.5	34.0
2	30.4	31.9	33.4
3	29.8	31.3	32.8
4	29.2	30.7	32.2
5	28.7	30.2	31.7
6	28.1	29.6	31.1
7	27.5	29.0	30.5
8	26.9	28.4	29.9
9	26.4	27.9	29.4
10	25.8	27.3	28.8
11	25.2	26.7	28.2
12	24.6	26.1	27.6
13	24.1	25.6	27.1
14	23.5	25.0	26.5
15	22.9	24.4	25.9
16	22.3	23.8	25.7
17	21.8	23.3	24.8
18	21.2	22.7	24.2
19	20.6	22.1	23.6
20	20.0	21.5	23.0
21	19.5	21	22.5

APPENDIX IV

Chemical Analysis of Feeds For Replacement Stocks

1.Basal Population:

Ration	Composition per 100 g				
	Dry matter	Crude protein	Calcium	Phospho-rus	Ether extract
Starter Crumbs	88.0	18.04	1.21	.70	-
Grower Pellets	88.0	16.98	1.42	.60	-
Breeder Mash	87.0	16.10	3.36	.70	3.80
Male Breeder Pellets	87.3	13.44	1.28	.65	2.82

2.Generation One:

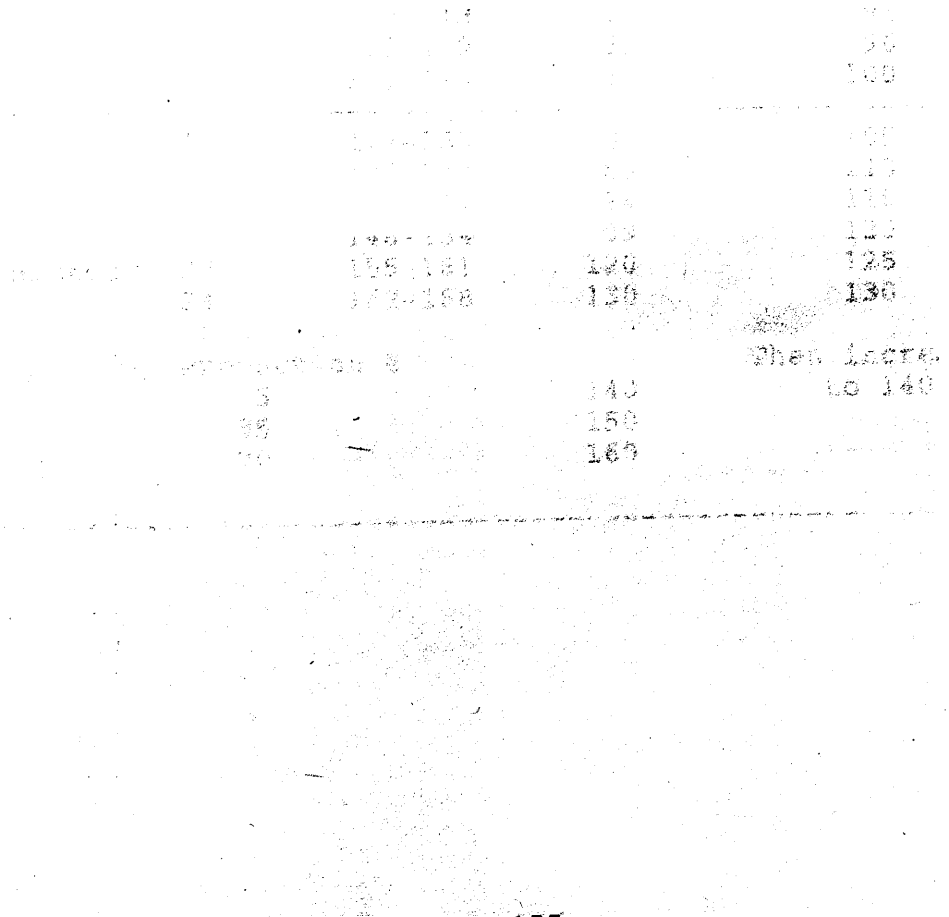
Ration	Composition per 100 g				
	Dry matter	Crude protein	Calcium	Phospho-rus	Ether extract
Starter Crumbs	87.7	18.85	1.19	.74	3.43
Grower Pellets	86.8	15.62	1.26	.62	3.24
Breeder Mash	89.4	17.16	3.18	.53	3.29
Male Breeder Pellets	87.9	15.90	1.32	.68	2.92

APPENDIX IV (CONT'D)

Chemical Analysis of Feeds For Replacement Stocks

3.Generation Two:

Ration	Composition per 100 g				
	Dry matter	Crude protein	Calcium	Phospho-rus	Ether extract
Starter Crumbs	86.7	18.63	1.23	.75	3.89
Grower Pellets	87.8	15.52	1.31	.69	3.02



APPENDIX V

Feeding Programme of Replacement Stocks

Ration	Age Weeks	Age Days	Female (g/bird/day)	Male (g/bird/day)
Starter	1	0- 7	Ad-Lib	Ad-Lib
	2	8- 14	Ad-Lib	Ad-Lib
	3	15- 21	Ad-Lib	Ad-Lib
	4	22- 28	45	42
	5	29- 35	53	51
	6	36- 42	58	55
Grower	7	43- 49	61	59
	8	50- 56	63	63
	9	57- 63	65	70
	10	64- 70	67	73
	11	71- 77	69	77
	12	78- 84	71	81
	13	85- 91	73	81
	14	92- 98	73	86
	15	99-105	73	91
	16	106-112	73	91
	17	113-119	73	96
	18	120-126	78	100
Breeder	19	127-133	84	105
	20	134-140	89	110
	21	141-147	94	115
	22	148-154	99	120
	23	155-161	120	125
	24	162-168	130	130
	Production %			Then increased
	5		140	to 140
	35		150	
	70		160	

APPENDIX VI

Chemical Analysis of Feeds For Broiler Progeny

1.First Broiler Progeny:

Ration	Composition per 100 g				
	Dry matter	Crude protein	Calcium	Phospho-rus	Ether extract
Starter Crumbs	87.9	21.97	.99	.68	4.89
Grower Pellets	87.0	21.58	.80	.64	6.76
Finisher Pellets	86.5	20.33	.70	.60	6.44

2.Second Broiler Progeny:

Ration	Composition per 100 g				
	Dry matter	Crude protein	Calcium	Phospho-rus	Ether extract
Starter Crumbs	86.7	23.15	1.02	.68	4.71
Grower Pellets	86.7	21.33	.86	.72	4.38
Finisher Pellets	87.4	21.24	.79	.63	4.95

APPENDIX VII

Chemical Analysis of Feeds For Broiler Progeny Under Different Temperatures

Ration	Composition per 100 g				
	Dry matter	Crude protein	Calcium	Phospho-rus	Ether extract
Starter Crumbs	87.6	23.83	.90	.66	4.45
Grower Pellets	88.2	21.34	1.08	.68	4.88
Finisher Pellets	87.6	19.88	1.06	.63	5.26

APPENDIX VIII

Table 1. Least-squares means and standard errors by line and sex for back score, body weight, and primary, secondary and tail length at 24 days of age for a sample of broiler progeny of the selected base generation population.

Main effects		No. obs.	Back score	Body weight (g)	Primary length (mm)	Secondary length (mm)	Tail length (mm)
Overall means		73	4.08±.18	578±7.1	85.4±.57	69.2±.84	23.7±.82
Line							
	Fast	37	4.60±.21 a	610±10.0 a	88.0±.80 a	74.1±1.14 a	29.5±1.16 a
	Slow	36	3.56±.21 b	546±10.1 b	82.8±.81 b	64.3±1.16 b	18.0±1.17 b
Sex							
	Male	36	3.32±.21 a	612±10.1 a	85.0±.81 a	64.4±1.16 a	17.7±1.17 a
	Female	37	4.84±.21 b	544±10.0 b	85.7±.80 a	74.0±1.14 b	29.8±1.16 b

[a,b]Means within main effects not followed by the same letter are significantly different ($P < .05$).

Table 2. Least-squares means and standard errors by line and sex for body weight (BW), feed intake (FI) and feed conversion (FC) at first and second periods of the trial of the broiler progeny of the selected base generation population.

Main effects	No. obs.$	24-day BW (g)	1-24 days FI (g)	1-24 days FC	35-day BW (g)	25-35 days FI (g)	25-35 days FC
Overall means	18	594±6	884±5.4	1.488±.014	1179±9.4	1221±12	2.095±.02
Line							
Fast	6	593±8 a	889±9 a	1.500±.02 a	1181±13 a	1234±21 a	2.102±.04 a
Control	6	590±8 a	885±9 a	1.502±.02 a	1170±13 a	1204±21 a	2.087±.04 a
Slow	6	600±8 a	878±9 a	1.463±.02 a	1187±13 a	1226±21 a	2.097±.04 a
Sex							
Male	9	628±7 a	921±8 a	1.468±.02 a	1265±12 a	1301±17 a	2.043±.04 a
Female	9	561±7 b	847±8 b	1.509±.02 b	1094±12 b	1141±17 b	2.148±.04 a

$ Each observation is the average of a pen, containing approximately 75 birds.

a,b Means within main effects not followed by the same letter are significantly different ($P < .05$).

Table 3. Least-squares means and standard errors by line and sex for body weight (BW) at 49-day age, and feed intake (FI) and feed conversion (FC) at the third period, and cumulative feed intake (CFI) and feed conversion of the whole trial Period (CFC), and 49-day weight as adjusted for CFI of the broiler progeny of the selected base generation population.

Main effects	No. obs.$	49-day BW (g)	36-49 days FI (g)	36-49 days FC (g)	1-49 days CFI (g)	1-49 days CFC	49-day BW adj. for CFI (g)
Overall means	18	1941±18	1880±27	2.478±.03	3986±34	2.056±.010	1942±8.6
Line							
Fast	6	1953±24 a	1872±38 a	2.439±.05 a	3995±50 a	2.049±.02 a	1950±14.9 a
Control	6	1934±24 a	1889±38 a	2.475±.05 a	3978±50 a	2.060±.02 a	1936±14.9 a
Slow	6	1938±24 a	1880±38 a	2.520±.05 a	3984±50 a	2.059±.02 a	1938±14.9 a
Sex							
Male	9	2117±21 a	2061±33 a	2.419±.04 a	4283±42 a	2.022±.02 a	2035±33.6 a
Female	9	1766±21 b	1700±33 b	2.537±.04 b	3689±42 b	2.090±.02 b	1848±33.6 b
Linear Regression Coeff.							.2768±.1054*

$ Each observation is the average of a pen, containing approximately 75 birds.

a,b Means within main effects not followed by the same letter are significantly different ($P < .05$).

* Significant at $P < .05$.

APPENDIX VIII (CONT'D)

Table 4. Least-squares means and standard errors by line and sex for starved weight, and plucked weight, carcass weight and fat weight as a percentage of starved weight, and fat weight as adjusted for starved weight of broiler progeny of selected base generation population.

Main effects		No. obs.	Starved weight(g)	% Plucked weight	% Carcass weight	% Abdo-fat weight	Adj. abdo-fat weight(g)
Overall means		138	1826±23.2	91.5±.15	68.5±.13	2.04±.05	37.1±1.00
Line							
	Fast	51	1862±28.8 a	92.1±.25 a	68.8±.20 a	2.12±.09 a	38.5±1.70 a
	Control	46	1836±29.7 ab	91.0±.26 b	68.2±.22 b	2.07±.09 a	37.3±1.70 a
	Slow	41	1782±30.7 b	91.4±.27 ab	68.4±.23 ab	1.95±.10 a	35.5±1.90 a
Sex							
	Male	68	1995±26.7 a	91.8±.21 a	68.9±.18 a	1.81±.08 a	32.0±1.80 a
	Female	70	1658±26.6 b	91.2±.21 b	68.2±.18 b	2.28±.08 b	42.2±1.80 b
Linear Regression Coeff.							.0252±.0067*

[a,b]Means within main effects not followed by the same letter are significantly different ($P < .05$).

* Significant at $P < .001$

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