A STUDY OF THE GROWTH AND EGG PRODUCTION IN LINES OF MEAT CHICKENS SELECTED FOR FAST AND SLOW FEATHERING

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PREFACE

A study of the growth and egg production in lines of meat chickens selected for fast and slow feathering was carried out in seven experiments. The stock used in this study were the progeny of the second, third and fourth generation of lines divergently selected for fast and slow feathering from a grand parent line of Ross broiler breeder carrying the K gene.

The selection experiment on a line of grand parent meat-type chickens having the slow, K, feathering gene was started in 1985 in the Poultry Science Department at the Scottish Agricultural College, Auchincruive. Edriss (1988) had taken the selection process to the third generation, while the selection of the fourth generation was part of this study.

The chicks which hatched on 2nd November 1989 (together with the chicks for the line crossing experiment - experiment 5 were intended for the respiration chamber experiment at the Institute of Animal Physiology and Genetics Research, Roslin. A health problem at Roslin forced postponement of the planned experiment for about 3 months. Therefore, we had about 7 days before the chicks were hatched to plan something different and thus a study on protein deposition (experiment 6) was started. Since we did not have chicks from the control line, the chicks from line crossing 1 (Fast Male x Slow Female and Slow Male x Fast Female) were therefore considered as controls. Furthermore,

the diet used was a commercial broiler starter diet.

Plasma blood samples from fast, control and slow feathering lines have been stored at -20^{o}C. Total plasma concentrations of thyroxine (T_4) and triiodothyronine (T_3) will be determined by radioimmunoassay in the laboratory of Dr. M.A. Mitchell, Avian Biotechnology Department, Institute of Animal Physiology and Genetics Research, Edinburgh Research Station, Roslin.

Blood samples from the fast and slow feathering lines and the k^{+} revertant will be sent to the laboratory of Dr. J.S.Gavora, Animal Research Centre, Agriculture Canada, Ottawa for DNA restriction fragment analysis as part of a broad program looking at the traits associated with the K gene from a number of genetic stocks around the world.

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SUMMARY

Seven experiments were carried out with fast and slow feathering lines of meat chickens in order to study the growth and egg production in these lines. The stock used in this study were the progeny of the second, third and fourth generation of lines divergently selected for fast and slow feathering from a grand parent line of Ross broiler breeders carrying the K gene.

Almost all experiments followed a factorial design and the factors were diet, age, line and sex. The experiments were carried out at the Scottish Agricultural College, except for experiment on energy metabolism which was carried out at the Institute of Animal Physiology and Genetics Research, Edinburgh Research Station, Roslin. Generally, the birds were housed in floor pens, except for the parents after 22 weeks of age and the experiment at Roslin where birds were housed in cages. Water and feed were provided *ad libitum* from day old until the end of experiments, except for replacement parents after 25 days of age.

The experiments were designed to provide information on sulphur amino acids and cystine requirements, feather growth, egg production, the genes affecting feathering, heat production, protein deposition and the partition of retained energy as protein and fat.

Some previous workers demonstrated that amino acids are not 100 per cent available in most common ingredients for poultry diets. Therefore, for experiment 1 and 2, per cent

digestible amino acids were used to convert total to available amino acids. The value for these were based on tables of analyses of raw materials containing mean values for the digestibility of different amino acids.

The objective of experiment 1 was to determine the effect of sulphur amino acid (SAA) intake on feather and body growth of male and female chickens in the fast and slow feathering lines. The sulphur amino acids content, and cystine in particular, of chicken feathers is high. Therefore, the intake of these amino acids has an important part to play in feather growth and body growth. The main findings of this study were SAA intake and feed conversion ratio (FCR) of the slow feathering line were significantly higher than the fast feathering line. FCR of the fast and slow feathering lines showed an improvement as the SAA level increased. The SAA requirement of the chicken for maximum efficiency was shown to be slightly higher than that for growth rate.

The SAA requirements for the various traits during period I (0-20 days of age) and period II (21-50 days of age) are based on the maximum level achieved:

For the fast line: Body weight period I, 7.8 g/kg (males), 7.3 g/kg (females); period II, 6.2 g/kg (males), 5.6 g/kg (females). Feather growth (both sexes) period I, 7.8 g/kg; period II, 6.7 g/kg. FCR period I, 9.2 g/kg; period II, 7.3 g/kg.

For the slow line: Body weight period I, 8.5 g/kg (males), 9.2 g/kg (females); period II, 7.3 g/kg (both sexes). Feather growth period I, 8.5 g/kg (males), 9.2 g/kg (females); period II, 6.7 g/kg (males), 7.3 g/kg (females). FCR period I, 9.2 g/kg; period II, 7.3 g/kg.

Experiment 2 was conducted to determine the effect of cystine intake on feather and body growth of male and female chickens in fast and slow feathering lines. The main findings were the slow feathering females had a higher cystine intake than the slow feathering males and both sexes of the fast feathering line. The requirement of cystine for feather growth was higher than that for body growth and FCR during period 0-15 days of age.

The cystine requirements for the various traits during period I (0-15 days of age) and period II (16-30 days of age) are based on the maximum level achieved:

For the fast line: Body weight period I, 3.1 g/kg (males), 3.5 g/kg (females); period II, 2.7 g/kg (males), 3.0 g/kg (females). Feather growth period I, 3.9 g/kg (both sexes), period II, 3.4 g/kg (males), 3.0 g/kg (females). FCR period I, 3.5 g/kg (both sexes); period II, 3.8 g/kg (males), 3.0 g/kg (females).

For the slow line: Body weight period I, 3.5 g/kg (both sexes); period II, 2.7 g/kg (males), 3.0 g/kg (females). Feather growth period I, 3.9 g/kg (males), 4.3 g/kg (females); period II, 3.4 g/kg (males), 3.8 g/kg (females). FCR period I, 3.5 g/kg (both sexes); period II, 3.8 g/kg (males), 3.0 g/kg (females).

The objective of experiment 3 was to obtain more information on feather growth of fast and slow feathering lines during the first 30 days of their life. All tracts of feathers were affected by the selection for fast and slow feathering. The main feature of slower feather growth is a delay in the commencement of feather growth in a particular tract rather than a deceleration of feather growth once started. One of the main findings was a correlation between feather lengths and body weight that was highest at 10 days of age. The condition of feathers at 14 days of age was a good time to distinguish between fast and slow lines and between sexes in both lines.

Fast feathering line had better feathering and body weight than the slow feathering line. Generally, females had better feathering than males.

Experiment 4 was conducted to obtain information on the performance of the fourth generation of fast and slow feathering lines. The main findings were that the beginning of moult in the fast feathering line was evident at 8 weeks of age, but in the slow feathering line moult was delayed for up to two weeks. Fast and slow feathering lines achieved maximum rate of lay at the same age, 32 weeks of age. However, the slow feathering line had a 6 per cent higher rate of lay than the fast feathering line.

After 4 generations of selection, males and females of the fast feathering line gained feather length, while the slow feathering line lost feather length. The divergent

selection had a more pronounced effect in the males than in the females.

The objective of experiment 5 was to determine if two major genes were segregating in the fast and slow feathering lines. The main findings of two experiments of line crossing were that a mutation may have taken place in the selection process. Selection may have lead to an increased frequency of the mutant gene and that gene may now be segregating with K to cause the observed effects in feather growth. The mutant gene may be K^{s}, one of the k allele series.

The objective of experiment 6 was to determine the protein deposition in feathers, meat and whole carcass (without meat) on males and females of fast and slow feathering lines over a wide range of body weights. The main findings were that the slow feathering line had more meat (% live body weight) and had a higher meat and carcass protein content, but lower feathers protein than the fast feathering line. However, no differences in abdominal fat weight was observed between lines.

Experiment 7 was conducted to study the influence of feathering on the thermal resistance of the feathers, heat production and efficiency of utilisation of metabolisable energy by the slow and fast feathering lines. The main findings were that the fast feathering line had a greater feather weight than the slow feathering line. The increase in feather weight appeared to be associated with the increase in thermal resistance of the feathers, but a decrease in feather surface temperature and heat production.

The fast feathering line had higher total energy retention than the slow feathering line. However, the partition of retained energy between fat and protein (% of retained energy) demonstrated that the slow line had a higher per cent of retained energy as protein (51.6% vs 42.4%) and lower per cent of retained energy as fat (48.4% vs 57.6%) than the fast line.

CHAPTER I. INTRODUCTION

Two important characteristics of meat type chickens are feathering and growth rate. There are two opinions about the relationship between feathering and body weight. Some workers have reported that fast feathering lines weigh more than slow feathering lines, while others claim that the relationship between feathering and body weight is not significant. Genetics and nutrition are the important factors which affect feather growth.

The major genes affecting feathering in the domestic fowl are K^n, K^s, K and k^+. These genes are responsible for the control of rate feathering and they are sex-linked genes. Other genes which also affect plumage development are the tardy genes T, t^s and t (Ram and Hutt, 1956; Somes, 1969; McGibbon, 1977). Siegel *et al.* (1957a) demonstrated genetic variation of feathering traits which was due to additive genes and rate of feathering has been shown to be highly heritable.

Feathers make up between 4 and 8 per cent of the live weight. They are composed chiefly of a protein called keratin (North, 1984) and the protein content of feathers is almost 82 per cent (Scott *et al.*, 1982). The sulphur amino acid (SAA) content of chicken feathers has been reported to be high (Block and Weiss, 1956) compared with other tissues. Methionine (as a supplement) is the sole dietary source of SAA while cystine is the major sulphur-bearing amino acid in feathers (Graber *et al.*, 1971).

The objective of the first two experiments was to determine the effect of SAA and cystine intake on feather growth of male and female chickens in fast and slow feathering lines, produced by divergent selection from a line carrying the slow feathering gene, K.

To study in more detail the differences in feather growth between fast and slow feathering lines, observations on feather growth during the first 30 days of age, and, feather growth from day old up to 14 weeks of age were carried out. Furthermore, the effect of the selection for feather growth on egg production and egg composition in the fourth generation of selection was also studied. In an attempt to determine if two major genes were segregating in the fast and slow feathering lines, two experiments of line crossing were carried out.

Since the protein content of feathers is high, if fewer feathers are grown it is reasonable to expect more protein to be deposited as meat. If the slow feathering line loses more heat, then more energy may be retained as protein than as fat. Therefore, two experiments were carried out to determine the influence of feathering on protein deposition, heat production and efficiency of utilisation of metabolisable energy by the slow and fast lines of chickens.

The results of this study are expected to give some information on the relative merits of fast and slow feathering meat chickens.

CHAPTER II. LITERATURE REVIEW

Growth is complex and influenced by many factors, including genetics and nutrition. If a young animal is to attain its genetic potential in respect of growth and development, it must receive adequate nourishment. To satisfy the animal's requirements, it must be supplied with sufficient quantities of feed of suitable quality and composition according to its stage of development. Therefore the first part of this chapter reviews nutrition in general. Although vitamins and minerals are important for growth, only energy, protein and amino acids will be stressed in this chapter. The reason is that a bird's feed intake is controlled by the concentration of energy in feed. Thus, the energy content of the diet must be the first considered in formulating to meet a desired intake of all essential nutrients. The concentration of protein and amino acids needed depend on the level of bird's feed intake. The amounts of feed used by the birds for their growth show which birds have the ability to utilise feed more efficiently.

Many researchers have reported that a higher sulphur amino acid (SAA) level is needed for maximum feed efficiency and the birds utilise relatively large amounts of SAA during the growing and reproductive portions of their life. Then, since SAA are usually the first limiting amino acids in poultry feed beside lysine, only sulphur amino acid nutrition is discussed.

Since the availabilities of amino acids in most common ingredients for poultry diets range from 80 to 90 per cent, therefore the reasons for using digestible amino acids in the formulation of diets will be reviewed.

The second part of this chapter is concerned with the growth curve and the effects of genetics, nutrition, environment and sex on growth. Since growth is the sum of the growths of the component parts of the carcass, whether they be meat, bone or skin, therefore body composition will be discussed in the third part of this chapter.

The birds used in this study were fast and slow feathering lines. Since this study is more concerned with the differences in feathering, therefore a review about feathering is needed. Furthermore, since it is known that SAA, especially cystine, are the major amino acids in feathers, the decision to limit the review to SAA is reinforced. In the fourth part of this chapter, the feather structure, feather composition, the effect of genetics, sex and SAA on feather growth and the effect of feathering on body growth and egg production are going to be discussed.

II.1. NUTRITION

II.1.1. Energy

Metabolisable energy has become the generally accepted method of expressing food values and energy requirements in poultry nutrition (Miller, 1974), since faeces and urine of the birds are voided together (McDonald *et al.*, 1981).

Metabolisable energy is a biological measurement dependent on the interaction between the animal, its food and its environment (Miller, 1974).

In order to study the extent to which the metabolisable energy of the food is utilised by the animal, it is necessary to measure either the animal's heat production or else its energy retention. Animal calorimetry is a sensitive method for determining small differences in heat production.

The heat may be measured by direct calorimetry or indirect calorimetry. In direct calorimetry a simple method is to place an animal in a small metal container, immersed in water-bath. The heat from the animal's body, conducted through the metal, warms the water by an amount which can be measured precisely. Measurement of heat production by indirect calorimetry makes use of the fact that heat is generated in the body by oxidation of a mixture of carbohydrate, fat and protein, a group of reactions which uses oxygen and produces carbon dioxide and nitrogenous excretory compounds. Measurement of oxygen used by the body in a given period, and carbon dioxide and nitrogenous excreta produced, can thus give an indication of the heat generated in this time (Stanier *et al.*, 1984).

Birds tend to eat satisfy their energy requirements if fed free choice. These animals tend to adjust their intakes to provide a constant energy intake. Thus, the energy level of the diet was first established for each species and age of poultry, and then the levels of other nutrients were determined based upon the established level of energy used

in the diet. When the energy level is increased feed consumption will decrease and the minimum level of other nutrients should be increased in proportion to the energy content. Similarly, if a lower dietary energy level is used, then proportionately lower levels of other nutrients should be used in the diet (National Research Council, 1984).

Factors affecting the response to dietary energy concentration are sex, age, breed, energy-to-protein ratio, and environmental factors. Males have a greater increase in metabolisable energy intake (kJ/d) than females, and this is reflected in a significantly greater response in body weight gain for males (Fisher and Wilson, 1974).

The metabolisable energy values of poultry feedingstuffs are commonly tabulated for birds which are kept for extended periods of time for breeding and those which are grown rapidly for meat production. The recommended metabolisable energy requirement for a broiler chicken (0-8 weeks of age) is 12.9 MJ/kg (Agricultural Research Council, 1975) or 13.3 MJ/kg (National Research Council, 1984). According to McDonald *et al.* (1989) the metabolisable energy requirement for broiler chicken is 12.75 MJ/kg (starter), 13.10 MJ/kg (finisher) and 11.50 MJ/kg (breeder).

Jackson *et al.* (1982a) found that increases in energy from 12.54 to 14.21 MJ/kg produced heavier but fatter birds. The results of Jackson *et al.* (1982b) demonstrate that total body protein is not affected by increases in dietary metabolisable energy between 10.87 and 15.05 MJ/kg, whereas body fat increases steadly with dietary metabolisable energy

(Fisher and Wilson, 1974).

The practical problem for the commercial feed manufacturer is to select a dietary energy level which minimises the cost of the feed but maximises the growth performance of the bird (Leclercq, 1986). Thus, the energy requirement may be defined as that amount of available energy that will provide for growth or egg production at high enough levels to permit maximal economic returns for the production unit.

There is an interaction between energy and protein. Since dietary protein is a source of dietary energy, and dietary energy is needed for protein deposition, then deposited protein represents part of the body's energy store. Feeding a diet containing a suboptimal amount of protein or an amino acid will lead to birds consuming an excessive amount of energy in order to optimise the intake of protein for growth. The excess energy consumed will then be deposited as fat. In contrast, diets containing excessive proportions of a nutrient such as protein may depress total feed intake and hence energy deposition but allow normal lean tissue growth. Since energy and protein interact, therefore the next part of this chapter will be focused on protein and amino acids.

II.1.2. Protein and Amino Acid

Protein: The dietary requirement for protein is actually a requirement for the amino acids contained in the protein (National Research Council, 1984). Because the young chick or poult consumes only sufficient food to satisfy its energy requirement, the amino acid contents of the food must be such that the animal receives sufficient of each essential amino acid and of non-essential nitrogen for optimal synthesis and deposition of tissue proteins. Thus the best method of expressing amino acid requirements may be in terms of the energy content of the diet. Since most of the essential amino acids are supplied as intact proteins in the diet, it is usual to express amino acid requirements as proportions of the dietary protein. The dietary protein may then be matched to the dietary energy. As dietary energy is increased, dietary protein must be increased (Scott, 1977).

The protein requirements represent the cumulative effects of amino acids, temperature, vitamins, growth rate and energy on the chick (Patrick and Schaible, 1981). The total requirement for protein can be broken down into two main areas: (1) that necessary for maintenance and (2) that necessary for tissue growth. In the early stages of life, the maintenance needs constitute a small proportion of the animals total needs but this proportion increases as the animal matures (Graber *et al.*, 1971).

Amino Acids: Some of the factors affecting amino acid requirements are temperature, genetics factors and several nutritional factors such as dietary concentration of energy, protein, vitamin B 12 and amino acid imbalance. Sex differences in amino acid requirements have also been proposed (D'Mello, 1978). The amino acid requirement will vary with the level of protein fed and the relative proportions of amino acids are more important than the protein level throughout the range of dietary adequacy from subnormal to supernormal protein levels (Bolton and Blair, 1986).

The essential amino acids must be present in the food protein in the same proper proportions at all dietary protein levels regardless of energy level, except when excess protein is supplied. Under these conditions the quantity of the most limiting amino acid does not increase proportionately with the increase in protein content (Nelson *et al.*, 1960).

Morris *et al.* (1987) stated that the requirement for an amino acid (expressed as a proportion of the diet) increases in direct proportion to the protein content of the diet until the protein supply fully satisfies the requirement for the second limiting amino acid. After this point, amino acid requirements remain constant as protein is increased, until another point is reached beyond which surplus protein causes an imbalance, which can be corrected by increasing the supply of the first limiting amino acid. For example: Fisher and Morris (1970) stated that the ratio

of methionine to crude protein should be a constant for all rations. They estimated the percentage methionine (X) on a per cent crude protein (Y) by regression equation:

$$Y = 0.0375 + 0.01235\ X + 0.0390\ a$$

a = 0 for the unbalanced protein series
a = 1 for the balanced protein series

which showed that the requirement for methionine increases with increasing protein content of the diet. The methionine requirement as a per cent of the dietary protein is estimated at 1.46 per cent.

The broiler chicken has high amino acid requirements per day to meet the requirements for rapid growth (National Research Council, 1984). The amino acid requirements of broilers expressed as a per cent of the diet are highest during the first week of age, and then decrease until the bird is marketed (Thomas *et al.*, 1978). Amino acid requirements may vary during different stages of life, depending upon the amino acid composition of the tissue being formed. During rapid feather development which has an amino acid pattern that is much different from chicken body tissues, the dietary amino acid requirements may show abrupt changes (Scott *et al.*, 1982).

II.1.3. Amino Acid Availability

The estimation of the feeding value of proteins is generally based on amino acid composition. The composition of mixed feeds and the requirement for the animals are nearly always expressed as total amino acids (Terpstra,

1979). Poultry have a very short digestive tract and also one that is particularly sensitive to pH changes. Some natural crude proteins are slowly digested, hence the available amino acids could be absorbed and deaminated before those slow to be released are available for absorption. The liver cannot store amino acids, so if the amino acids are not absorbed when needed, they cannot be used for protein synthesis (Patrick and Schaible, 1981).

When diets are formulated on the basis of feed analysis data, the assumption is generally made that amino acids are 80-90 per cent available from the feedstuff protein (National Research Council, 1984). Since most requirements have been established using proteins in which the amino acids were similarly available, requirements are corrected for availability. When the amino acids in a particular ingredient are less than 85 per cent available, special care must be taken in diet formulation to consider only the available amino acids (Scott, 1977)

Published figures for amino acid contents of individual feedstuffs have, in general, been obtained by physicochemical method of analysis. Because these determine the total amount of amino acid present they are of limited value only, since not all of each amino acid in a protein is made available to the animal in the course of digestion, absorption and metabolism (Papadopoulos, 1985).

Gous (1986) has the opinion that in publishing results of response experiments it should be made clear whether total or available nutrient concentrations have been used.

The Institute National de la Recherche Agronomique (1987) suggested that the measurement of digestibility (total or ileal) ought nevertheless to constitute a useful criterion for availability in the future and it is possible to foresee tables of analysis of raw materials containing mean values for the digestibility of different amino acids.

II.1.4. Sulphur Amino Acids

Poultry need relatively large amounts of sulphur amino acids (SAA) during the growing and reproductive portions of their life. Sulphur amino acids are among the most critical as they are frequently the first limiting amino acids in poultry diets. Therefore, for efficient broiler production it is important to be able to estimate the total SAA requirement (Engler *et al.*, 1985).

The SAA requirement of the chick for maximum efficiency is slightly higher than that for growth rate (Nelson *et al.*, 1960; Combs, 1964). Bishop and Halloran (1968) concluded that growth increases curvilinearly with increased consumption of total SAA until it is physiologically impossible to consume more. Total SAA consumption in excess of the asymptote amount will depress body weight. Furthermore, Boomgaardt and Baker (1973) reported that addition of SAA to the diet resulted in a linear decrease in body fat. This would perhaps indicate that as SAA levels were increased, more 'effective' protein became available.

It is known that in the chick methionine can be converted into cystine but the reverse is not possible. Bishop and Halloran (1968) stated that cystine can account for as much as half of the total SAA requirement and that the balance must come from methionine. Furthermore, Graber and Baker (1971) reported that when the total SAA requirement was expressed as a per cent of the diet, the need for a methionine-cystine combination was less than for all methionine. This did not appear to be a result of metabolic inefficiency but rather due to the fact that feed intake was maximised at a lower concentration with the SAA combination than with methionine alone.

Most commercial poultry diets are marginal in total SAA and hence are supplemented with methionine. Moran (1980) reported that cystine is more limiting than methionine. No consideration is given to cystine other than adding it to the methionine of the feedstuffs to arrive at the total SAA level. Although cystine is utilised as efficiently as methionine (Wheeler and Latshaw, 1981), Graber and Baker (1971) reported that cystine addition resulted in a greater feed intake than that resulting from a comparable addition of methionine. Also, when common levels of supplementation are compared, cystine promoted greater weight gains than methionine. Then, they suggested that the cystine present in diets may have a profound effect on the total SAA requirement expressed as a per cent of the diet.

Boomgaardt and Baker (1973) demonstrated growth responses (g/day) of young chicks in relation to dietary methionine plus cystine (%) and metabolisable energy concentration (Fig. 2.1). The utilisation of the SAA, however, was not influenced by the three energy levels (Fig.2.2), as illustrated by the single response curve which is obtained when weight gain is plotted versus daily intake of methionine and cystine. These results support the general rule that the dietary energy exerts an effect primarily through variations in food intake and not through changes in amino acid utilisation.

Nelson *et al.* (1960) stated that the SAA requirement of chicks was directly related to dietary protein concentration. They claimed that the requirement for SAA was 35.1 g/kg protein in diets ranging from 190 to 270 g protein/kg. More recently, Mendonca and Jensen (1989) reported that the SAA requirement for body weight gain increased as dietary protein content increased, indicated a requirement of 38 g SAA/kg protein in diets ranging from 200 to 280 g protein/kg.

Jensen *et al.* (1989) reported that the broilers fed on a diet with 200 g protein/kg and 13.2 MJ/kg from 3 to 6 weeks of age required 7.8 g SAA/kg to obtain optimum body weight gain, food efficiency and minimum abdominal fat content. This value was found to be higher than the value of 7.2 g SAA/kg recommended by National Research Council (1984).

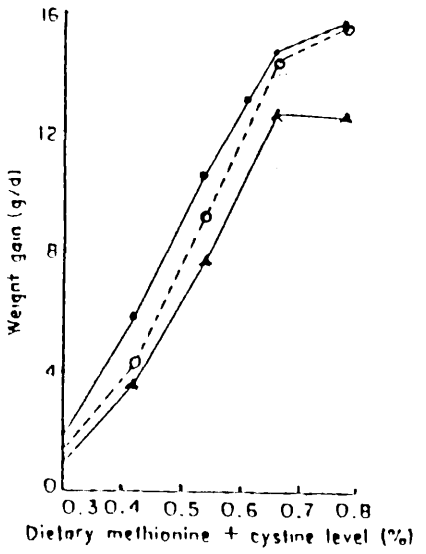


Figure 2.1. Growth responses (g/d) of young chicks in relation to dietary methionine + cystine (%) and metabolisable energy concentrations. Energy levels (MJ/kg): (•) 10.9, (o) 12.6, (▲) 14.2. Data from Boomgaardt and Baker (1973)

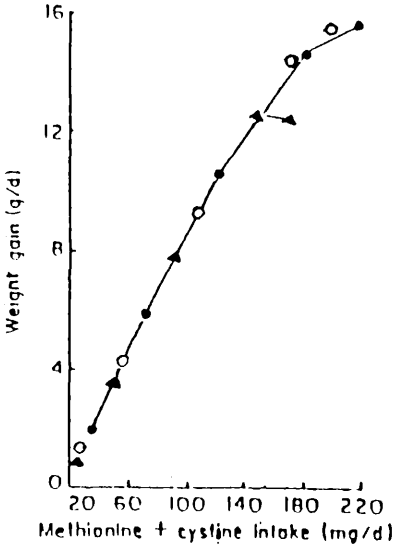


Figure 2.2. Chick growth (g/d) and methionine + cystine intake (mg/d) at three dietary levels of metabolisable energy (MJ/kg): (•) 10.9, (o) 12.6, (▲) 14.2. Data from Boomgaardt and Baker (1973.

The SAA requirement of broiler chickens seems to have a wide variation. Some factors contributing to this variation probably are the problem of biological availability of SAA in different dietary energy levels in the diets and genetic differences of the birds which were involved in experimentation.

II.1.5. Feed Intake and Feed Efficiency

Feed intake is influenced by a number of factors including environmental temperature and dietary energy concentration (D'Mello, 1978). Since dietary energy level is the main factor controlling feed intake of broilers, evaluation of the effect of dietary protein level on feed intake is not justified without also accounting for the interaction between these two nutrients. Therefore protein and energy yielding ingredients are by far the two most important components of diets influencing feed intake (Summers, 1974). Boorman (1974) indicated that the quality and quantity of the dietary protein can also markedly influence feed intake.

A deficiency in the level of dietary protein will influence feed intake in that the bird will over-eat in an attempt to obtain more protein, while an excess of dietary protein may lead to a decrease in feed consumption. Thus performance depends on the energy content of the diet and/or amino acid balance (Summers, 1974). According to Boorman (1974) feed intake on a balanced low protein diet is greater than on a diet deficient in one amino acid (imbalanced

diet). The chicks fed on a balanced low protein diet may eat more than those on an imbalanced high protein diet. It should be noted that while severe deficiencies of amino acids cause decreases in feed intake, moderate deficiencies, insufficient to markedly affect growth, may cause an increase in feed intake. Summers (1974) indicated that almost any nutritional deficiency will alter feed consumption. If the deficiency is slight, an increase in feed intake often takes place, while if the deficiency is severe enough a decrease in feed intake takes place.

As the protein level of ration decreases and food intake increases, feed efficiency deteriorates (Combs, 1962). Nesheim (1973) stated that the feed efficiency improved with each increment of an amino acid mixture up to the highest level fed. Associated with this was a decrease in carcass fat as the amino acid level was increased. The effect of amino acid level on lipogenesis seems to be an important aspect of the effect of protein level on feed efficiency. Morris *et al.* (1987) reported that growth rate and efficiency of feed utilisation to 21 days of age responded to increasing dietary protein contents up to about 230 g crude protein /kg diet.

Overall, feed efficiency is one of the top factors considered when evaluating breed differences and management decisions, since feed costs still comprise about 70 per cent of the total cost of production. Therefore, the factors influencing feed intake and feed efficiency such as energy and protein in the diet have to be adequate and balanced.

II.2. GROWTH

II.2.1. Definition and Curve of Growth

Growth is a phenomenon of change- in size, weight, shape, composition, and structure (Fuller, 1969). Body growth includes the multiplication of cells (hyperplasia) or an increase in cell size (hypertrophy) (Hafez, 1969). The increase in cell numbers and cell size in animals occurs both prenatally and postnatally. Prenatal growth is essentially an increase in the number of cells. Following birth, hyperplasia continues for a brief period accompanied by the initiation of the increase in cell size. Prenatal growth and early postnatal growth are very significant in determining final growth potential (Hansel, 1985). Animal growth, as it is usually referred to in the animal science literature, concerns the increase in skeletal and muscle size resulting from cell hypertropy. This phase of growth is strongly hormonally regulated (Wagner and Jochle, 1986).

The growth of one part of an animal is usually controlled by the activities of other parts. All parts of the animal do not stop growing simultaneously. The growth rate of each organ and tissue increases to a maximum and then declines. These maximum rates of growth occur in a definite sequence. For example, the central nervous system reaches its maximum growth rate first, bone follows, and muscle and adipose tissue reach their maximum last (Hafez, 1969).

A typical growth curve of a broiler chicken is approximately sigmoid shaped (Fig. 2.3). The curve starts from nearly zero and body weight then increases gradually to some mature body weight. Growth has two phases, an accelerating phase from hatching and decelerating phase. A point of inflexion between two phases in the growth curve is the point at which growth rate is maximum (Wilson, 1977). The point of inflexion of the growth curve usually follows soon after the attainment of puberty and the secretion of steroid hormones at the time of sexual maturation is itself responsible for changing the pattern of growth (Foxcroft, 1980).

Growth retardation is associated with the failure of DNA to replicate and cellular protein synthesis is reduced (Hafez, 1969). McCance (1977) has reported that if growth is delayed, and if after a period of the time animals are subsequently fed to capacity, catch up or compensatory growth will occur, and they may or may not regain their predestined size. Wilson (1977) gave one definition of compensatory growth as that when the animal becomes small for its age due to some factors decreasing growth, and then subsequently when that animal tries immediately to grow faster, for a time, than normal larger animals at the same age.

Many factors exert an influence on growth. They include genotype, nutrition, environment (Maciejowski and Zieba, 1982; Spencer, 1986) and sex (Maciejowski and Zieba, 1982) and there is interaction between those factors and endocrine

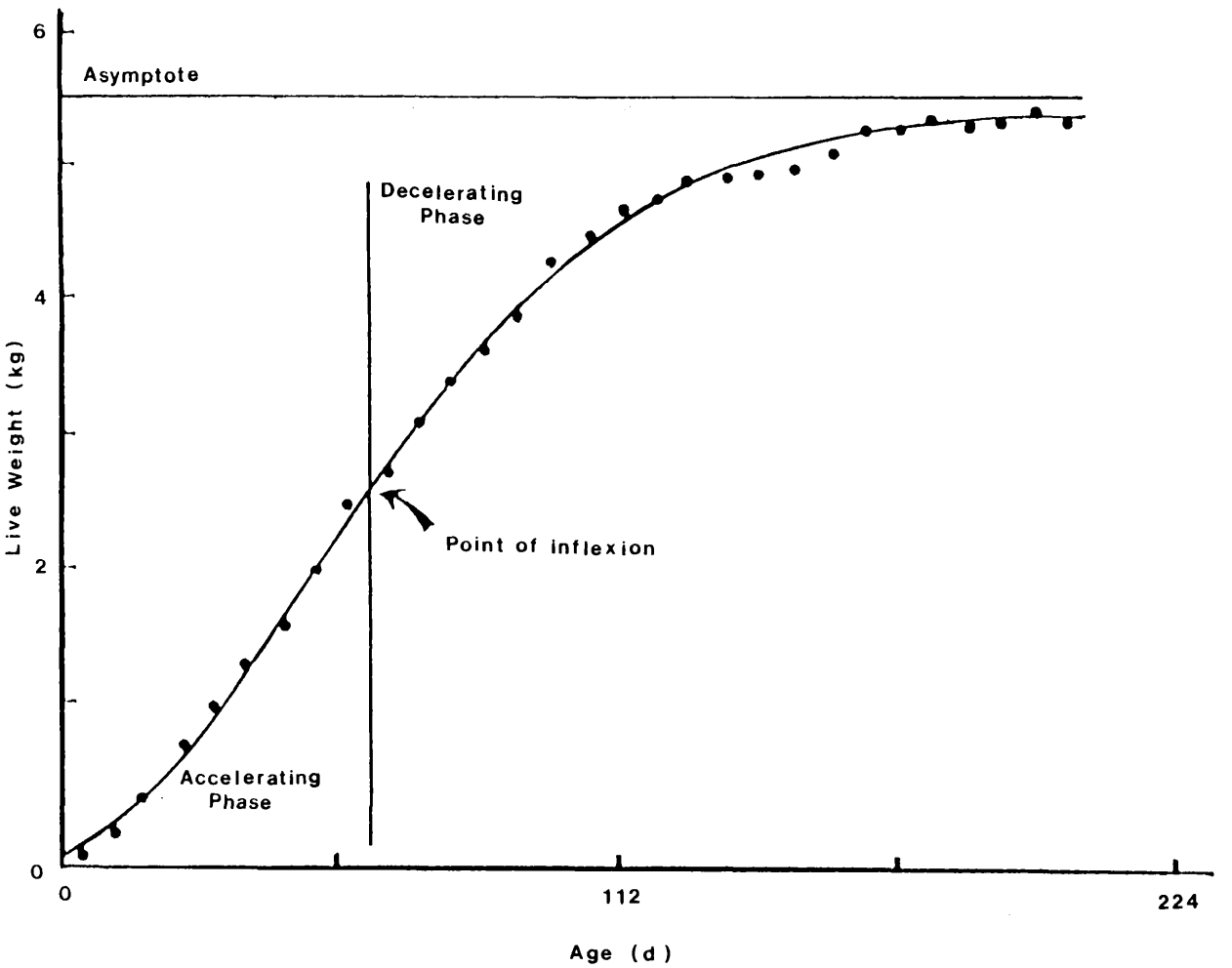


Figure 2.3. A typical growth curve of a broiler chicken (Wilson, 1977)

secretions (Scanes and Harvey, 1984). The effects of those factors on growth will be discussed in the next parts.

II.2.2. Effect of Genetics on Growth

The aim of the applied geneticist is to design the most efficient programme to select for the inherited improvement of a desirable character. Body weight or weight gain are the measures of growth usually used in selective breeding (Falconer, 1960). These variables are normally distributed and are assumed to be affected by many genes each with a small effect and by several environment factors.

Growth variation and the resulting product of breeding are influenced by mating systems. Crossbreeds show heavier body weight in comparison with pure bred individuals. Conversely, inbreeding results in a slower growth rate of offspring (Maciejowski and Zieba, 1982). Results of selection experiments, evaluation of strain crosses and heritability estimates in meat-chickens indicate that body weight and growth rate are moderately to highly heritable (Siegel and Dunnington, 1985).

Inherited improvement of meat production in animals is usually attempted by selection for growth. However, this often produces undesirable effects, such as the increase in deposition of fat. Therefore selection for growth together with lean meat yield has been given more attention in the 80's. Breeders of meat chickens are now selecting for meat yields, feed efficiency and against fat as well as growth. This has lead to chickens with a leaner carcass.

II.2.3. Effect of Nutrition on Growth

There are many factors which control growth, one of these is nutrition. Nutritional requirements vary with the species, breed, age, reproductive stage, social stress, disease, parasites, and physical environment. Various physiological mechanisms are involved (Hafez, 1969). If a young animal is to attain its genetic potential in respect to growth and development, it must receive adequate nourishment. The young chicken needs all nutrients such as amino acids, vitamins and minerals together with energy-yielding ingredient for growth and maintenance in a greater concentration than adult chickens (Scott, 1977). To satisfy the animal's growth requirements, it must be supplied with sufficient quantities of feed suitable quality and composition, according to its stage of development (Maciejowski and Zieba, 1982). Spencer (1986) said that improving the utilisation of feed (through influencing appetite, digestion and absorption of feedstuffs) and manipulating the endocrine factors involved in growth, are areas holding considerable potential for increasing the efficiency of animal production.

Nature has accorded a very high priority to the process of growth. Undernutrition of young growing animals results in continued growth, even if the undernutrition is severe enough to cause a decrease in body weight. Some protein deposition and bone growth continue, and the energy is provided from the reserves of fat in the body of the animal (Blaxter, 1962). Any lack or deficiency of essential

nutrients will affect the growth and performance of the chicken. If there is a severe deficiency of a single essential nutrient the animal will lose weight and eventually die (Scott, 1977).

Growing animals are characterised by high rates of synthesis of tissue proteins, the form in which a large fraction of their dietary protein is retained (Fuller, 1969). Increased dietary protein intake appears to be the only factor, when associated with an increase in protein accretion, that substantially increases protein synthesis in the body as a whole (Reeds, 1988). The fact that protein, in addition to its key role in growth, can be used as an energy source, means that in some circumstances the utilisation of dietary protein is improved when extra dietary energy is supplied. This is the so-called ''protein sparing'' action of dietary energy (Fuller, 1969).

Flatt and Moe (1969) explained that the net efficiency of the utilisation of energy for growth is affected by the partial efficiencies as well as the total amounts of fat and protein deposited. For normal growth, however, the energy intake must exceed the animal's maintenance needs and the energy value of the body tissue increases with age because juvenile growth contains more water, protein and bone mineral and less fat than does later growth. Increased levels of feed intake result in accelerated growth rates, but may also increase the ratio of fat to protein, which is deposited as body gain.

As energy intake increases with the rising dietary energy more protein is utilised for lean growth and less broken down for other purposes. With a low energy diet the excess protein is broken down, but instead of being utilised as a direct source of additional energy it is deposited as fat within the carcass (Wells, 1963). According to Kielanowski (1965), the energy cost of protein deposition in chickens is 7.74 kcal (32.38 kJ) of metabolised energy per gram of protein. The deposition of 1 g of fat required 15.64 kcal (65.44 kJ) of metabolised energy.

That the diet provides the essential nutrients in appropriate forms and in the amounts needed, are important for optimum functioning of all body cells. Maximum growth and efficiency of feed utilisation in young chicks are achieved when diets of appropriate energy content are precisely balanced with other nutrients.

II.2.4. Effect of Environmental Temperature on Growth

Birds have the ability to maintain their body temperatures over a wide range of environmental temperatures, in which the heat loss is the same as the heat production. According to Whittow (1986), if such a thermal balance is not achieved, the deep body temperature decreases when heat loss is greater than heat production. Heat loss to the environment is by the processes of radiation, conduction, convection, and evaporation of moisture.

The optimal temperatures for maximum growth in the domestic chicken are 32-34^{o}C at 1 day old, falling by about 0.5^{o}C/day to 19^{o}C at 32 days old. The maximum weight gain for chicken takes place in the temperature range 18-24^{o}C (Barrott and Pringle, 1950; Charles and Spencer, 1976). The most important way in which animals react to a change in their climatic environment is by adjusting their voluntary intake of feed. Heat production increases directly with the amount of feed consumed, therefore this behaviour can greatly modify the relation between the animal's environment and its energy metabolism and growth. Since the major influence of the environment is on energy exchange, it might be expected that the highest weight gain would be attained at the temperature at which energy retention is at a maximum (Fuller, 1969).

Brody (1945) remarked on the effect of high temperatures in depressing growth in chickens, an effect which is the direct consequence of diminished feed intake. According to Fuller (1969) growth rate is less impaired by cold weather when animals have feed *ad libitum* than when they are restricted to the same amounts of feed in all circumstances. Mount (1980) explained that when more heat production is required to maintain deep-body temperature in a cold environment, less feed energy is available for growth if feed intake is limited.

With meat-producing animals, the relation between environmental temperature and growth rate is of considerable economic importance, since a cool and a hot environment may

result in decreased efficiency of nutrient utilisation and poorer growth.

II.2.5. Effect of Sex on Growth

The influence of sex on an animal development can be the effect of genetic differences between male and female or due to the presence of sex hormones (Maciejowski and Zieba, 1982). The rate of growth of male chickens is greater than that of females, but the energy equivalent of the growth increments is greater in pullets than in cockerels (Mitchell, 1962; Freeman, 1963). At day old pullets and cockerels show no significant difference in weight, but the difference steadly increases with time. So that by eight weeks of age broiler cockerels are on the average 10 per cent heavier than pullets, and at the age of 20 weeks, the difference amounts to 20 per cent. The fact that in poultry males are heavier than females appears to be due to genetic differences other than hormonal factors. Sometimes the marked differences in body weight between adult cocks and hens are due not to sex alone but also to selection and feeding (Maciejowski and Zieba, 1982).

According to Wells (1963), when female chicks were supplied with additional energy and protein, they were unable to utilise as much of the additional protein for lean growth and so failed to show a marked decrease in carcasse fat. The females were incapable of utilising more protein for lean growth, which therefore remained almost constant as

the energy level increased, but they consumed excess energy, which was deposited as fat in the carcass . The males were capable utilising the additional energy to convert even more dietary protein into body protein, though the rate of conversion fell off as the dietary energy level approached 1500 calories per lb (13.8 MJ/kg), and then the birds were beginning to show an appreciable increase in carcass fat content.

The male synthesises less adipose tissue than the female, and is consequently able to convert feed to body weight more efficiently since the production of 1 kg of adipose tissue requires more feed than the production of 1 kg of muscle or bone (Hafez, 1969).

It seems that there are differences in growth rate and nutrient utilisation between males and females. Therefore, it is often advantageous if males are kept separately with females and fed different diets.

II.2.6. Effect of Thyroid Hormone on Growth

Hormones directly or indirectly influence growth by altering biochemical reactions, and many of them influence the size of specific tissues and organs (Carlson, 1969). The expression of growth is the result of interactions between nutritional, environmental, genetic factors with the endocrine secretions. These interactions can be manipulated by management practices to maximise growth rate and feed efficiency and to optimise carcass characteristics (Scanes

and Harvey, 1984). Thyroid is one of endocrine glands which is necessary for normal growth and development (Ringer, 1965) and also has a specific effect on maintenance energy production (Kielanowski, 1965) and the effects are reviewed here as an example of hormonal action.

The thyroid hormones are released from the thyroid as the amino acids thyroxine (T_4) and triiodothyronine (T_3). Once in the blood they are again bound to protein. Depressed thyroid activity as a consequence of goitrogen administration is reflected in reduced metabolic rate, increased fat deposition, and in some cases growth depression (Ringer, 1965)

Plasma concentrations of T_3 appear to be positively related to growth rate. This relationship is observed between individuals within a strain (Kuhn *et al.*, 1982) as well as between strains (Lauterio *et al.*, 1986). Stewart and Washburn (1983) found a significant negative correlation between T_3 and carcass fat within lines in chickens. Decuypere and Buyse (1988) reported that the greater fatness of thyroid-deficient birds may be related to lower metabolic energy loss.

Scanes and Harvey (1984) concluded that thyroid hormones are required for normal growth. Although the relative role of T_4 or T_3 is not fully established, it is likely that T_4 exerts its effect after conversion to T_3. Supranormal concentrations of T_4 have no major effect on growth while those of T_3 depress the growth rate.

II.3. BODY COMPOSITION

Most of the published research on body composition of the broiler has involved comparisons of strains, age, sex, nutrition and environmental temperature. Body composition for chickens is normally considered from a starting point of a defeathered carcass. There is however, some evidence that variations in feather cover have an influence on the composition of the carcass beneath.

II.3.1. Effect of Genetics

a. Chemical Body Composition

Selection for increased body weight in chickens over many years (Cunningham and Morrison, 1976; Brody *et al.*, 1984; Soller and Eitan, 1984) has resulted in birds with increased per cent body fat and decreased per cent protein, moisture, and ash compared to unselected controls or birds selected for reduced body weight. In the 70s and 80s researchers investigated the effects of single trait selection on body composition of broilers to identify the underlying causes of increased carcass fat content.

Pym and Solvyns (1979) reported that after five generations of selection the proportions of carcass water (678g/kg) and protein (187g/kg) were highest in lines selected for increased body-weight gain and lowest (636, 180 g/kg respectively) in lines selected for increased feed consumption, while the proportion of fat was reverse.

Some researhes reported the effect of feathering on body composition. Somes and Johnson (1982) who studied featherless broilers (scaleless, sc/sc) reported that the sc/sc broilers had more protein and mineral content and less fat than the feathered broilers. Hanzl and Somes (1983) found that Naked Neck birds had a significantly lower total lipid value in the carcass than for wholly-feathered birds. Zein-el-Dein *et al.* (1984) who studied the Naked Neck chickens found that the percentage of subcutaneous and intermuscular fat was significantly lower in Naked Neck birds than the normal feathered chickens. Ajang (1989) who studied in fast and slow feathering lines (the same as those used in this broad study) reported that the slow feathering line had a higher water and protein content and lower fat content than fast feathering line.

Line differences in carcass composition seem not appreciably altered if birds were killed at equal weights rather than equal ages (Pym and Solvyns, 1979). Yet according Jorgensen (1989), the difference in fat content would probably have been less if the birds had been slaughtered at the same liveweight because fat retention increases with increasing liveweight.

b. Physical Body Composition

Bouwkamp *et al.* (1973) reported that the progeny of Hubbard (male) x Arbor Acre (female) gave greater breast and back and smaller drum and wing yields than progeny of Vantress (male) x Arbor Acre (female). Furthermore, the eviscerated yield and component parts of five commercial

broiler crosses were evaluated by Merkley *et al.* (1980). They concluded that the fresh eviscerated carcass yields were not significantly influenced by the cross of broilers, but the relative yields of parts among crosses differed. The Ross crosses (Ross x Hubbard, Ross x Arbor Acre) had a significantly larger proportion of breast and a lower proportion of legs than the Hubbard crosses (Hubbard x Hubbard, Hubbard x HN, Hubbard x Shaver). The amount of abdominal fat was the largest single significant source of variation among the carcass yield of broiler crosses.

Cahaner *et al.* (1986) selected against abdominal fat and found a better carcass yield in their low fat line, together with a higher proportion of breast in the carcass, less skin, and the same amount of bone. Leenstra and Pit (1987) who selected lines against abdominal fat or for improved feed efficiency found that both exhibited higher carcass yields than the control growth selected line, higher breast meat and leg yields, but lower yields of skin + subcutaneous fat. Recently, Ricard and Touraille (1988) concluded that selection against fatness in broiler is able to bring about a significant modification in chicken carcasses: a decrease of up to a half in total body fat; a large decrease of abdominal fat deposits; a higher slaughter yield; and a higher breast meat yield.

Zein-el-Dein *et al.* (1984) reported that meat yield of the eviscerated carcass is superior for the Naked Neck chickens compared with normal feathered chickens. Merat (1986) concluded that the higher proportion of muscles and

lower proportion of skeleton were a consistent feature of the eviscerated carcass of Naked Neck birds compared with normally feathered birds. Molanapour (1988) and Ajang (1989) concluded that the slow feathering line had higher percentages of total meat and breast meat but lower percentages of abdominal fat and skin than the fast feathering line.

II.3.2. Effects of Age and Sex

Age and sex have been found to influence greatly body composition. As an animal grows older there are changes in its size, physical and chemical compositions.

a. Chemical Body Composition

Edwards *et al.* (1973) showed the tremendous differences in body composition that develop between male and female chickens with age. The carcass composition data show a gradual decrease in moisture content and increase in fat content with age regardless of sex. Evans *et al.* (1976) concluded that protein content increased as the broilers increased in age. The females contained more fat and less protein and water than males (Edwards *et al.*, 1973; Evans *et al.*, 1976, Pym and Solvyns, 1979).

b. Physical Body Composition

Females had a higher percentage of total meat as well as a greater meat to bone ratio (Hayse and Marion, 1973; Evans *et al.*, 1976). Merkley *et al.* (1980) reported that the

relative yield of breast and back was greater in female broilers than in male, but the relative yield of legs and thighs was greater in the males. Howlider and Rose (1989) concluded that females had a greater skin and breast meat weight than the males.

Grey *et al.* (1982) showed that up to 56 days of age, males had a slightly higher eviscerated yield. There was no significant difference between the sexes beyond this age. Only age had a significant effect on the yield of breast. When the total meat from the muscle groups was considered, differences between sexes were small up to 76 days of age. The increased yield in the male after this was due to the increase in the thigh and drumstick rather than a proportionate decrease in the yield of the breast muscle. The yield of thigh and drumstick was generally higher in the male, particularly after 76 days of age. The development of the thigh muscle in the male is quite marked, a 4 per cent increase in addition to a 2 per cent increase in the drumstick between 76 and 175 days of age must be related to the increased live body weight at these ages. According to Sonaiya *et al.* (1990), sex significantly affected bone proportions and leg meat proportion at 34 and 54 days of age and only affected breast meat proportion at 54 days of age.

Overall, most researches agreed that females were fatter than males. However, the difference of body composition between sexes is small and is more related to their age.

II.3.3. Effect of Nutrition

Body composition varies in relation to dietary protein:energy ratio. As the ratio of energy to protein in the ration is widened, the energy intake and carcass fat deposition are increased and the water content of the carcass is decreased (Donaldson *et al.*, 1956). Summers *et al.* (1965) found that carcass protein increased linearly as dietary protein increased from 200 to 260 g/kg. Jackson *et al.* (1982a) reported that increased dietary protein decreases tissue fat deposition by broilers. Maurus *et al.* (1988a,b) reported that high protein levels support the deposition of protein in the meat parts and decline the degree of fatness. Recently Kirchgebner (1989) demonstrated that with rising protein:energy ratio protein content increased from 17.9 to 20.6 per cent, fat content decreased from 19.3 to 8.7 per cent.

Supplementing a diet with limiting essential amino acids result in changes in carcass protein and fat content (Moran, 1971; Thomas *et al.*, 1973). With regard to protein deposition, Sibbald and Wolynetz (1985) showed that the essential amino acid requirement for maximising protein accretion was higher than that required for maximum weight gain of broilers. This, in general, confirms the report of Summers and Leeson (1985) in demonstrating that although the yield of edible meat was similar for diets ranging in protein content from 160 to 220 g/kg, there was greater yield of protein with the 220 g/kg protein diet.

A comparison of diets containing 170, 200 and 230 g/kg dietary protein demonstrated that birds on the 170 g/kg protein diet had less carcass protein and more carcass fat than the higher protein diets. However, supplementation of the 170 g/kg protein diet with methionine and lysine resulted in weight gain and carcass composition values similar to the higher protein diets. At similar body weights, bird fed the higher levels of protein or birds fed diets supplemented with essential amino acids resulted in higher levels of carcass protein accretion. By using yield of edible breast protein as a measure of dietary protein utilisation, it should be possible to measure more precisely essential amino acid adequacy in practical broiler diets (Summers *et al.*, 1988).

Since the major cost of broiler production is for their diets, energy, protein and amino acids in the diets for broilers therefore have to be adequate and balanced to achieve maximum edible meat yield and lower cost of production.

II.3.4. Effect of Temperature

The effect of temperature on body composition has been reviewed by Howlider and Rose (1987). They reported that for each degree rise in rearing temperature, as hatched broilers have a 0.81 per cent and 1.6 per cent increase in abdominal fat and total fat respectively and a 0.15 per cent decrease in moisture content of the carcass. They concluded that

there is no relationship between the protein content of the carcass (% of liveweight) and rearing temperature. According to Swain and Farrel (1975), as temperature increased feed consumption and growth rate declined, and there was a significant increase in fat, and a decrease in water content of the carcasses.

Howlider and Rose (1989) reported that the broilers reared at 21°C had more breast meat than those reared at 31°C. Recently, Sonaiya *et al.* (1990) concluded that there was no significant effect of temperature on body weight at 34 days of age and on dressing proportion of commercial broilers at 34 and 54 days of age.

The effect of temperature on body composition is also associated with the feathering. According to Somes and Johnson (1982) who studied featherless broilers (scaleless, sc sc) at high temperatures (34°C), the featherless birds can perform much better than feathered birds. In this case, the featherless birds are less severely stressed by heat and thus eat more than the feathered birds. This results in more rapid weight gain, greater final weight and eviscerated yield is greater because they lack feathers. They also have a higher per cent of protein and a reduced fat content. Hanzl and Somes (1983) demonstrated that the Naked Neck (Na Na) birds performed better than either Na na or na+ na+ birds at a temperature of 38°C. They concluded that there were no differences between the three genotypes in New York dressed yield in the hot room. However, chemical body composition data indicated that NaNa birds contained similar

protein, less lipid (particularly in cool room, 21°C), and more moisture and ash (particularly in hot room, 38°C) than the $na^{+}na^{+}$ birds. Molanapour (1988) who studied the physical body composition in fast and slow feathering lines reported that the percentage of total meat was significantly greater at 20°C compared with 30°C. A higher percentage of breast meat was found under the temperature regime of 20°C but the percentage of leg meat was conversely higher at 30°C. More abdominal fat was found in birds under the temperature regime of 30°C.

Although temperature is an important factor in influencing overall growth, it seems that temperature has an indirect effect on body composition, by interacting with nutrition and genotype of the birds.

II.4. FEATHERS

II.4.1. Feather Structure

Birds are almost completely covered with feathers and this makes them different from other vertebrates. Feathers make up between 4 and 8 per cent of the live weight of the bird, the variability being related to age and sex; older birds and males have a lower percentage (North, 1984). There are various types of feathers. Quill feathers are found on the wings and tail, while contour feathers are the outer feathers covering the wings and body. Plumule feathers lie next to the body and are fluffy to provide the insulation needed to retain body heat in the winter and minimise

absorption of heat during the hot weather. A hair like feather, the filoplume, appearing to be very rudimentary and biologically undeveloped is located close to the body with no specific function identified (Moreng and Avens, 1985).

A feather is composed of a root called the calamus. A long quill or shaft, known as the rachis gives rigidity. Barbs extend from the quill, barbules extend from the barbs and barbicels extend from the barbules. All parts except the quill tend to mesh together in the flat portion of the feather (North, 1984). The anatomy of the feather is shown in Fig. 2.4.

The various wing feathers are not easily distinguishable in the standing bird. However, when the wing is spread out (Fig. 2.5), the parts can be identified. The wing shoulder is that part nearest the wing's attachment to the body. The wing front is the front most edge of unfolded wing extending to the tip. The wing bow is the upper surface portion of the wing just posterior to the wing front. The wing coverts are two rows of feathers extending out from under the wing bow feathers and covering the bases of the secondaries, providing a smooth and streamlining effect. The primary coverts are those toward the wing tip; the secondary coverts extend from the proximal portion of the wing. The primaries are the long flight feathers forming the posterior edge of the outer wing section; the secondaries of the proximal section. The axial feather is located between the primaries and secondaries (Moreng and Avens, 1985).

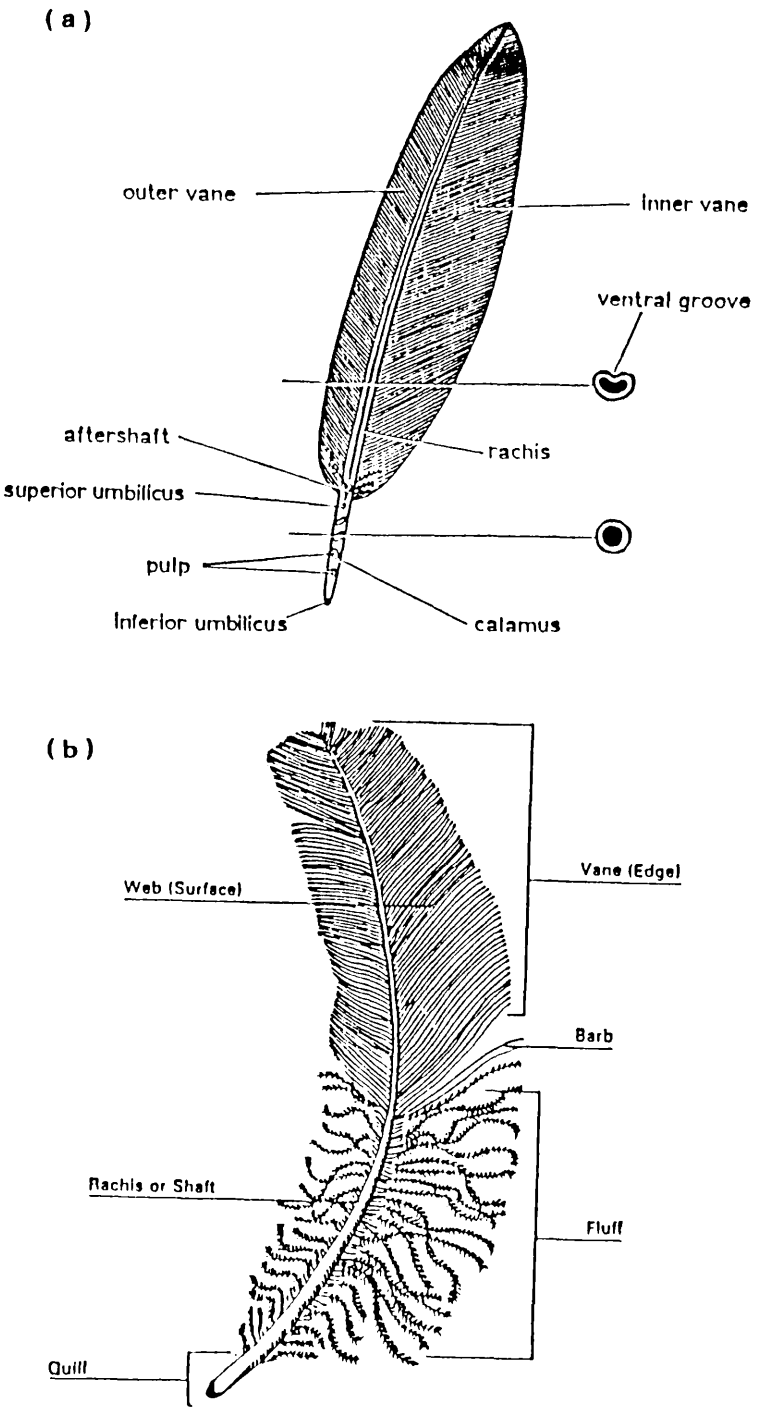


Figure 2.4. Anatomy of the feather (a. North, 1984, b. Moreng and Avens, 1985).

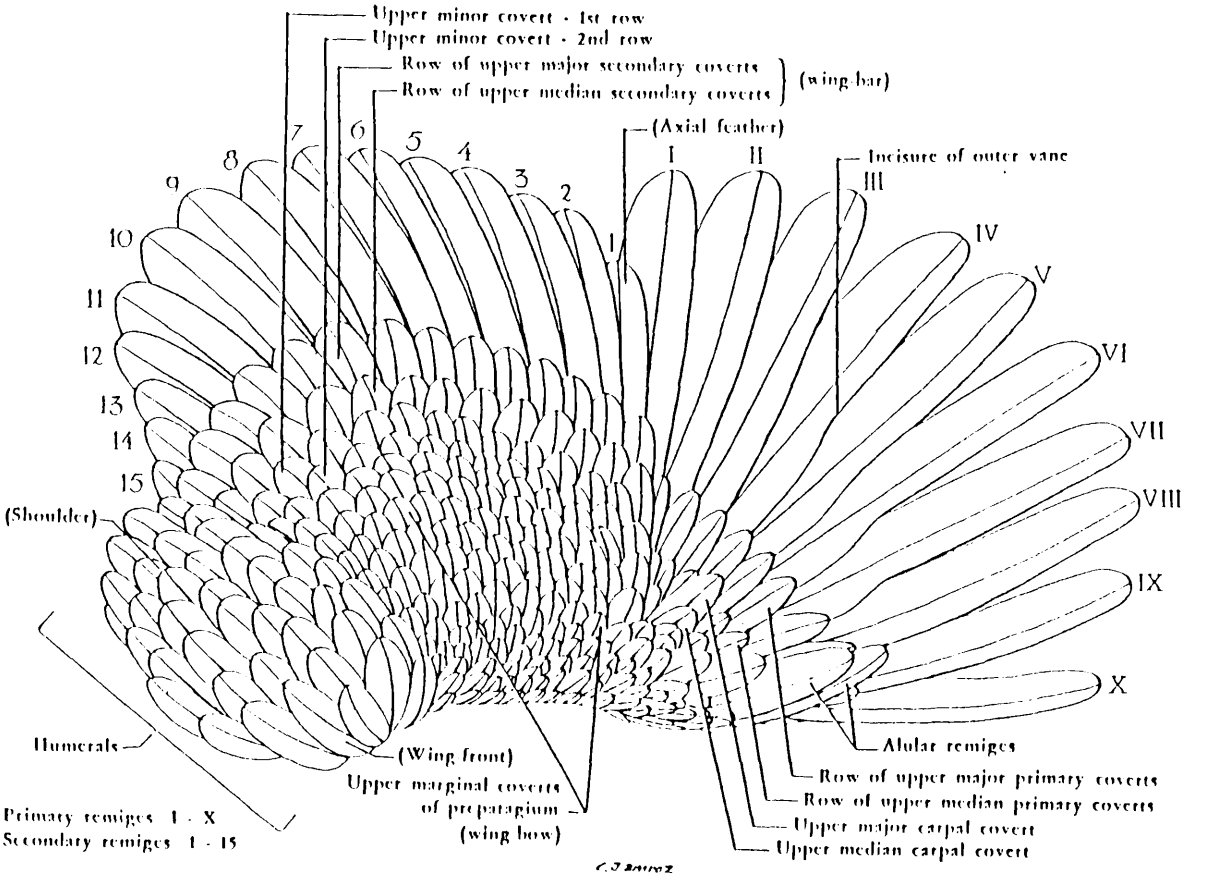


Figure 2.5. Plumage of the extended left wing of the Single Comb White Leghorn chicken - dorsal side (Lucas and Stettenheim, 1972).

II.4.2. Feather Composition

The composition of raw chicken feathers is about 90.7 per cent crude protein, 1.3 per cent ether extract (lipids) and 7.9 per cent moisture (McCasland and Richardson, 1966). The essential amino acid composition of the mixed proteins of chicken meat, eggs and feathers, compared with that of the proteins of a corn-soybean meal laying ration, is presented in Table 2.1.

Table 2.1. Essential amino acid composition of the proteins of chicken meat, eggs, feathers and a corn-soybean meal laying ration *

Amino Acids	Chicken tissue	Egg	Whole raw feathers	Corn-soybean ration
	g/kg Protein			
Arginine	73	64	73	67
Cystine	25	62	74	18
Histidine	40	23	6	24
Isoleucine	39	50	64	51
Leucine	65	83	85	96
Lysine	96	71	16	49
Methionine	19	32	5	17
Phenylalanine	36	47	55	52
Threonine	34	50	47	41
Tryptophan	10	14	7	12
Valine	44	65	89	51

* Scott *et al.* (1982)

Fisher *et al.* (1981) who studied broiler males reported that only the methionine, threonine, isoleucine and valine content of feathers change with bird age. Thus, the concentration of methionine in feathers decreases with bird age, while that of threonine, isoleucine and valine

increases. They indicated that feather growth and feather composition can be influenced by dietary specifications.

Keratins are the proteins of feathers, hair, claws, beak, hoofs and horns, and are very insoluble and indigestible. The S-S bonds within the keratins may contribute in large part to the insolubility and indigestibility of these proteins (Scott *et al.*, 1982). Keratinisation in feathers takes place while the cells are flushing and assuming their final shape, not afterward (Lucas and Stettenheim, 1972). Keratins are very rich in cystine (McDonald *et al.*, 1981) but low in methionine (Table 2.1.).

II.4.3. Feather Growth

Feather growth starts in a sheath of the feather follicle imbedded in the skin (Fig. 2.6). At the base of this tubular pocket in the epidermal layer of the skin there is a specialised group of cells from which many successive generations of feathers will be derived (Moreng and Avens, 1985).

In Figure 2.7, the development of feathers above the skin is shown. As it grows, it pushes the natal down out of the follicle on its tip. The new feather is tightly furled inside a sheath while it forms. As it appears above the skin, it has a long conical shape with a blunt tip and a slightly moist surface. A feather at this stage in any generation is often called a pin feather. Starting at the

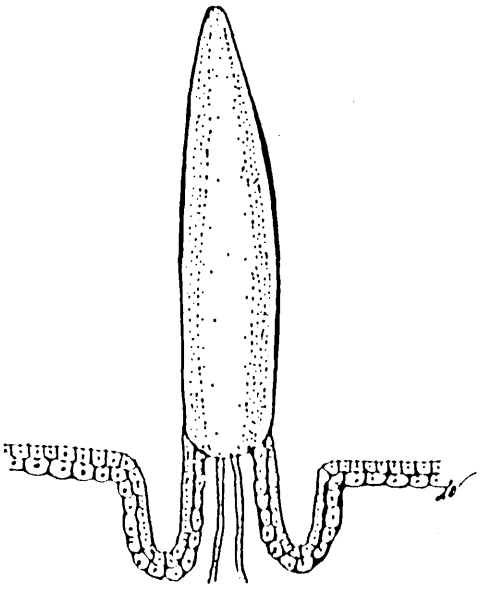


Figure 2.6. Specialised cells of the feather follicle consisting of a core from the dermal layer of skin and a thin covering of cells from the outer epidermal layer (Moreng and Avens, 1985).

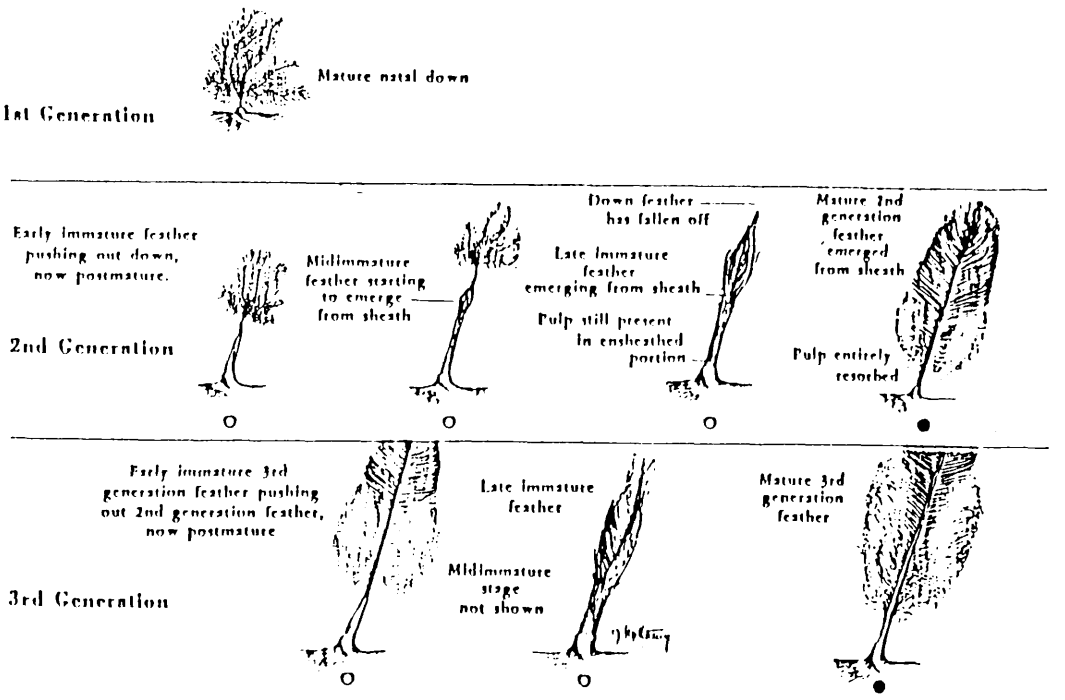


Figure 2.7. Development of feathers above the skin (Lucas and Stettenheim, 1972).

tip the sheath dries and flakes off. This allows the feather to begin to emerge. The natal down is usually knocked off the juvenile feather by the time the latter reaches this stage. Presence of the natal down is no criterion for the stage of development of the juvenile feather. The new feather continues to lengthen and emerge from its sheath; the pulp appears to recede as it is resorbed at the tip. The late immature stage of development is that which lasts from the time a feather has emerged at least half way from its sheath until it is fully grown. A feather is considered fully grown (mature) when its vanes are entirely free of sheath and when the pulp disappears below the surface. It takes up to about ten days for the pulp still in the calamus to be completely resorbed, depending on the length of the calamus (Lucas and Stettenheim, 1972).

When the chick hatches, it has almost no feathers. Except for the wings and tail, it is covered with down. Soon the down grows longer, and most of the down attachments to the skin develop a shaft. Within a few days the shaft erupts, and the web of feather makes its appearance (North, 1984).

II.4.3.1. Effects of Genetics and Sex on Feather Growth

The growth of feathers is controlled by major genes on a few loci and by many minor genes. Among the genes are involved in feathering in the chicken are two series of alleles, k and t.

On the one hand, the k series is sex-linked and consists of K^n, K^s, K and k alleles which express different rates of feathering ranging from extremely slow to rapid feathering. The K^n allele is the most dominant in this series. Feather development is greatly delayed by this gene. At one day of age primary flights are either lacking or much smaller in size compared to the coverts. Birds are naked during juvenile life and poorly feathered as adults (Somes, 1969). The second allele of the series is a dominant K^s gene. At one day of age the primary flight feathers are much shorter than the coverts. Feather development is greatly delayed during early juvenile life, but birds of both sexes have complete back feathering by 12 weeks of age. This gene has no effect on adult plumage (McGibbon, 1977).

Primary flights and covert feathers are all about the same length at one day of age in birds with the K allele. But at eight to twelve days of age the tail feathers have not yet developed. Over-all feathering is later for these birds than those with the rapid allele, k. The K gene also has no effect on adult plumage. The most recessive allele of this series is the k allele. At one day of age the primary flights are much longer than the coverts. At eight to twelve days of age the chicks have developed tails. The chicks completely feather at a much more rapid rate than those with the other three alleles (Ram and Hutt, 1956).

On the other hand, the t series are autosomal genes and consist of t, t^s and T which are called tardy, retarded and normal genes. Each allele is dominant on the others in

favour of normal. So, the T allele is the most dominant one in the series. Warren (1933) reported a simple autosomal recessive gene (t), which modifies the expression of the ordinary early feathering in White Leghorn chicks. At one day of age, the normal number of well developed secondary flight feathers was reduced to the first three secondaries. The retarded gene cannot be identified in the adult birds. Jones and Hutt (1946) demonstrated the t^s 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.

Since the heritability values for feather growth are high (> 0.40) (Siegel *et al.*, 1957a; Edriss, 1988), the inheritance is mainly through additive gene effects. Therefore, selection at an early age would be effective in improving the feathering in slow feathering chicken populations.

Radi and Warren (1938) found that tails are likely to appear earlier in females than in males. Hays and Sanborn (1942) reported that tails started about three days earlier in females than males. Furthermore, Hays (1952) reported that since females actually showed a greater tail length than males, it seems probable that the endocrine system operates to regulate tail length resulting in a sex difference that is significant.

Siegel *et al.* (1957b) indicated that the sex-linked gene for late feathering (K) is incompletely dominant to its allele and shows a dosage effect at least during the first three weeks of life. A highly significant difference existed between KK males and K-females. When KK and Kk males were compared, a highly significant difference was again obtained. In both cases the KK males were poorer feathered than either Kk or K- chicks. In five out of six comparisons during the first three weeks of life between Kk males and K- females no significant differences was obtained at 12 days of age.

Although the predominant feature of the recessive gene is to cause the feathers to grow more rapidly during the first six to nine weeks of the chick's life, the difference between slow and fast feathering is obvious at the time the chick is hatched, but only in the relationship between the length of the primary wing coverts and primary remiges (North, 1984).

McDougald and Keshavarz (1984) studied feather growth in genetically slow feathering broilers at 10, 17, 24, 31 and 52 days old. They demonstrated that the males initially had shorter average lengths of primaries and secondaries than females at ten days of age, but grew faster than those on female chicks. By 31 days, however, the wing feather lengths for males and females had converged. Male chicks had longer feathers than female chicks after 31 day of age. The back feathers for males emerged more slowly than females. But by the 52nd day, the back feather length and back scores

of the males and females were about the same. While most strains of such slow feathering males produce fully feathered birds by the time they reach five or six weeks of age, often because of stress and hot weather, some males may be poorly feathered with excessive pin feathers at market time (North, 1984).

II.4.3.2. Effect of Sulphur Amino Acids on Feather Growth

The sulphur amino acid (SAA) content of chicken feathers is high (Block and Weiss, 1956; Nitsan *et al.*, 1981) when compared with other tissues. Graber *et al.* (1971) found that the constant methionine requirement during the time period two to eight weeks of age may reflect the intense growth of feathers. Moreover, since cystine is the major sulphur-bearing amino acid in feathers, the sparing ability of cystine for methionine would be expected to increase with increasing age.

Keratin is the only protein where extensive amounts of cystine are needed, hence, variation in feather formation is expected to have a large influence on cystine requirements (Moran, 1980). Wheeler and Latshaw (1981) reported that rapid feather growth began toward the end of the second week of life (12 to 14 days). The onset of feathering is early and rapid in the broilers and the maintenance requirements for SAA (primarily cystine) of a fully feathered broiler are comparatively small due to the current practice of marketing at such an early age. Methionine, then, may have

increasing importance for growth of broilers through the finishing period.

McDonald (1958) showed that the chicken's ability to synthesis cystine from methionine is subject to genetic control. Sheridan and McDonald (1963) suggested the possibility that selection for increased body weight has favoured birds with better cystine synthesising ability.

Using a dietary methionine content of 3.1 g/kg and varying the finishing diet cystine content from 3.5 g/kg to 4.5 g/kg for males and 2.8 to 3.6 g/kg for females, Moran (1980) obtained significant responses in the quantity of feathers produced. For males an increased amount of feathers was found when cystine approximated 4.5 g/kg. Females responded likewise at a lower level than that required for males (3.2 g/kg). This result is a converse of that indicated for the starting period and, presumably, occurs because of differences in the degree of feather growth. One can debate the need to meet the cystine requirement accurately because the only tissue altered was keratin.

II.4.3.3. Feathering and Body Growth

The birds which feather rapidly weigh more at broiler ages than those birds which feather slowly (Glazener and Jull, 1946; Hutt, 1949). Weight at hatching time in an early feathering (k) group of New Hampshire chicks was highly significantly heavier than that of a late feathering (K) one. The differences at two, five, and ten weeks of age

were also highly significant (Saeki and Katsuragi, 1961). Hutt (1949) suggested that the sex-linked, rapid feathering gene not only speeds up body processes but may also give the better feathered birds better insulation resulting in less loss of heat. Thus, more of the total nutrient intake would be used for growth.

Jull (1952) reviewed earlier published reports on the relationship between feathering and body weight. In general, the birds which were better feathered usually had a slightly larger body weight. The relationship between feathering and body weight seemed to be at a maximum during the first few weeks after hatching. Hurry and Nordskog (1953) concluded that genes controlling feathering also influence the growth rate. This conclusion was obtained from the estimation of phenotypic and genetic correlations between feathering and body weight in Barred Plymouth Rock and New Hampshire chicks. On the contrary, other reports, which described the relation between these two characteristics, concluded that the characters were weakly correlated (Radi and Warren, 1938; Godfrey and Farnsworth, 1952).

Godfrey and Farnsworth (1952) indicated that the influence of the sex-linked, recessive gene for rapid feathering was limited to the feather follicle. The differences in body weight of rapid feathering birds and slow feathering birds was primarily due to reasons other than differences in feather weight. Sheridan and McDonald (1963) suggested that competition between the body of the bird and its feathers for common subtrates may exist during

the first few weeks of the bird's life. Rapid feathering birds were found to be more uniform for body weight than the slow feathering ones. Although the analysis yielded no significant relationship between rapid feathering and body weight, an interesting trend was observed. They found that the slower feathering birds had been heavier at five weeks of age whereas at ten weeks, the rapid feathering birds were heavier. This could possibly be due to competition between the body of the bird and its feathers for common substrates.

The sex-linked gene k appears to improve the average degree of feathering at broiler age without influencing its variation. On the other hand, this gene was not found to increase significantly body weights at eight weeks of age. (Hurry and Nordskog, 1953). Regarding the influence of this gene on variance in body weight the two sexes did not respond alike. The sex-linked slow feathering cockerels were significantly more variable than the sex-linked fast feathering cockerels. The effect of the sex-linked gene on body weight variance in the females was not statistically significant (Hurry and Nordskog, 1953).

Moreng and Avens (1985) reported that rapid feathering and rapid growth are closely associated. Besides that, less feather picking and cannibalism is found when birds are rapidly feathered. Therefore, the broiler producers prefer rapid feathering more than slow feathering birds. Dunnington and Siegel (1986) examined chickens from a commercial broiler stock to ascertain whether the presence of the sex-linked early (k+) and late (K) feathering alleles

caused a difference in feather cover (weight of feathers) at 147 and 196 days of age. There were no differences between early and late feathering females for absolute feather weight or feather weight as a percentage of body weight. Early feathering males had heavier body weights and feather weights than early feathering females, but there were no differences between sexes for percentage of feather weight. Females at 147 days of age had a greater percentage of feather weight than at 196 days of age due to an increase in body weight but not in feather weight. Younger females had a proportionately greater amount of feather weight than older ones.

Means of 28-day body weight were significantly greater for genotypic groups among the males having the slow feathering gene. Means of the female genotypes were significantly less than those of the males but did not differ significantly from each other. Body weight gain during the 28 to 52 day period and body weights at 52 days of age were affected by genotype. Slow feathering male genotypes had significantly greater mean weights than the rapid feathering types. In females, the difference in favour of the slow feathering genotype, was not statistically significant (Lowe and Merkley, 1986).

Generally, it seems that there are two different opinions about the relationship between feathering and body growth. The first opinion is the birds which feather rapidly weigh more at broiler ages. But, the other opinion is that there is no difference in body weight associated with rate

of feathering. Therefore, the effect of feathering on body growth is not clear yet. However, according to Godfrey and Farnsworth (1952), the action of the gene seems to take place in the feather follicle and is not concerned with general body growth.

II.4.3.4. Feathering and Egg Production

Not many reports have discussed the effect of feathering on egg production traits. The mutant genes involved in plumage distribution, Na (Naked Neck) and sc (scaleless) and the genes involved in rate of feathering, K^n, K and k effect on egg production will be discussed.

Smith and Lee (1977) found a lack of significant differences for egg laying and mean weight between Nana (Naked Neck birds) and na^+na^+ (normal feathered birds) genotypes. Horst (1980) reported briefly that at high ambient temperature the Naked Neck gene is associated with a 7.4 per cent gain in total egg mass during the first 3 months of production. According to Merat (1986), laying rate and feed efficiency for egg production did not differ significantly according to genotype, but the egg mass produced in 28 days showed an advantage for Naked Neck layers, significant at the 5 per cent level.

In Abbott and Asmundson's (1962) work the data showed that the egg number (hen caged basis) to 350 days of age of scaleless (sc sc) birds was less than that in the normal birds, but the eggs laid by scaleless birds was 3 grams more

than those laid by normal birds.

Somes (1975) who studied the sex-linked delayed feathering gene, K^n, in the chicken demonstrated that the K^n-females did not start to lay until the fourth week of a 24 week period egg production (24 to 48 weeks of age), had only reached 50 per cent production by the 16th week and never did reach 100 per cent production, while the k-females started to lay and were at 50 per cent production in 2 weeks and at 100 per cent production in 6 weeks. However, once egg production commences there is no difference hen day egg production between the two genotypes.

Merat (1990) reviewed the effect of sex-linked feathering on egg production, and concluded that most reports show no association with the K or k+ alleles. He also concluded that in Dunnington and Siegel's (1986) data no differences associated with feathering alleles appears for laying traits. Hence if a depressive effect of the K allele on egg production is noticed in some cases it is not general.

Havenstein *et al.* (1987) observed that the k+/- daughters from K/- dams produced at a 2.8 per cent lower hen-day egg production rate, laid 6.9 fewer eggs and had an egg weight 0.6 g less than eggs from k+/- daughters of k+/- dams. According to Bacon *et al.* (1985, 1986) who work in White Leghorn strains, linkage of the K allele with an endogenous proviral gene (ev-21), which may interfere with immune response of the progeny against leukosis virus transmitted through the egg, suggests an explanation for

lower egg production and/or survival rate of this progeny.

CHAPTER III. GENERAL MATERIALS AND METHODS

III.1. Experimental Objectives

The stock used in the various experiments were the progeny of the second, third and fourth generation of lines divergently selected for fast and slow feathering from a grand parent line of Ross broiler breeders containing the K gene. Production of the second and third generations were carried out by Edriss (1988). The production of the fourth generation was completed as part of this study.

The sulphur amino acid (SAA) content of feathers, particularly that of cystine, is high. Therefore the difference in feathering between the fast and slow lines may result in differences in SAA or cystine requirements for growth. For this reason, two experiments were carried out. Experiment 1 was conducted to investigate the effect of dietary SAA (methionine and cystine) content on feather growth in the progeny of fast and slow feathering lines from the second generation parents. Furthermore, experiment 2 was conducted to determine the effect of dietary cystine content on feather and body growth in the progeny of fast and slow feathering lines from the third generation parents.

The difference in feathering between lines were expected to have an effect on feather or body growth curves. To obtain more information on the feather growth of fast and slow feathering lines, experiment 3 was carried out during the first 30 days of life.

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. In experiment 4, the divergent selection of fast and slow feathering lines for the fourth generation was carried out from two hatches. At 25 days of age, predicted tail length from the multiple regression equation was employed as the criterion for selection of fast feathering birds within the fast line and slow feathering ones among the slow line.

After 4 generations of selection, two experiments of line crossing (experiment 5) were conducted to investigate the major genes contributing to feathering of the fast and slow feathering lines.

The protein content of the feathers is very high. If there are differences in feather weight between fast and slow feathering lines, the fast feathering line may deposit relatively more protein in the feathers than the other tissues. An experiment (experiment 6) was conducted to determine the protein deposition in feathers, meat and whole carcass (without meat) on males and females of fast and slow feathering chickens over a wide range of body weights.

It is known that the feathers play a vital role in conserving heat and so have an influence in economic terms on the production of poultry meat. Probably there is an effect of feather cover on the heat production of the birds, and an experiment (experiment 7) was conducted in respiration calorimeters for the duration of the normal life

of a broiler.

III.2. Experimental Design

Almost all experiments followed a factorial design and the factors were diet, age, line and sex. The exception was experiment 7 which was performed as balanced incomplete randomised block design.

III.3. Chick Production

A mating is carried out by artificial insemination, two times a week. In experiments 1, 2, 3, 6 and 7, pooled semen from 8 males of each line were used for inseminating 48 females with those semen from the same line.

In experiment 4, in each line, a total of eight potential males were used as sires of the next generation. In fast and control lines, six females were assigned to mate with one male. Due to a small number of females in the slow line, four females were assigned to mate with one male. Pedigree mating was carried out by artificially inseminating each hen with semen from a specific sire. If the semen production of a sire was not enough to cover all the females which they were assigned to, therefore the priority of the second artificial insemination was for those females which did not get any semen at the first insemination.

In experiment 5, two line crossing experiments were carried out. Each hen was inseminated with semen from a specific sire. Since in the first study from 8 various matings not many offspring were obtained, therefore the second study of line crossing (two matings) was carried out to get more offspring and (statistically) more meaningful results.

The eggs were collected every day. After sterilisation of egg-shells in a formaldehyde fumigator, the eggs were incubated for 18 days. On the 19th day, all eggs were transferred to hatching trays according to their line. On the 22nd day of incubation, the hatch was taken off and all chickens were wing banded according to lines. Then, all chicks were vent-sexed, the numbers of males and females noted.

III.4. Housing

Almost all the experiments were conducted in floor pens. The floor of the pens was covered with about 100 mm of fresh wood shavings. In the experiments 5 and 6, in the first two weeks, the chicks were raised in battery brooders, then they were either killed at the end of experiment 5, or they were moved into a floor pen (experiment 6)

Experiment 7 was carried out at the Institute of Animal Physiology and Genetics Research, Edinburgh Research Station, Roslin which was the site of the respiration

chambers. One day old chicks (the day after hatching day) were delivered from the Scottish Agricultural College to the Institute of Animal Physiology and Genetics Research, and then put into battery brooders up to ten days of age. Thereafter they moved into cages (in pairs).

Generally, the birds were raised in a floor pen. The brooding heat was provided by one gas brooder within each pen during the first week. Temperature in the first day was about 32-34^{o}C and decreased 1^{o}C every two days until 21^{o}C was reached. It was then kept constant until the end of the experiment. The lighting pattern was 23.5h light : 0.5h dark. The intensity of the light was 20 lux during one to five days of age, thereafter it was reduced to two lux. Feed and water were available *ad libitum*.

III.5. Diets

The birds in experiment 1 were fed six different levels of SAA diets, while the birds in experiment 2 were fed five different levels of cystine. The diets in experiment 1 and 2 were formulated on the basis of digestible amino acids in the ingredients the information for which was obtained from Janssen *et al.* (1979). The feeds were formulated on a computer using linear programming. Digestible amino acid contents were in fixed proportion to protein content in each feed on a calculated basis. Samples of all experimental diets were taken at all periods (I and II) to determine dry matter, protein, ether extract, calcium and phosphorus by

the Analytical Services Unit.

The birds in experiments 3, 4, 5, 6 and 7 were given commercial broiler starter and grower rations. Furthermore, the birds in experiment 4 were fed a commercial breeder ration at the beginning of the pre-production period.

III.6. Recording Procedure

Recordings of body weight, feather lengths and feather score were involved in all the experiments. The procedure was as follows:

a. **Body Weight**

Day old chicks were weighed individually. Subsequently, every three (experiment 7), five (experiment 2), ten (experiments 1 and 3) or fourteen (experiments 4 and 5) days the chickens were weighed individually depending on the kind of experiment. While, in experiment 6, the birds were weighed at certain ages.

b. **Feather lengths and Scores**

Feather growth was determined by linear measurement and feathering score of some feather tracts by visual assessment. All of the measurements and scoring were done by the same person.

Primary and secondary wing feathers. The length of the number two primary and secondary wing feather (numbering proximally from the axial) were measured by ruler in mm from

the base of the pin feather to the farthest point of emergence (Siegel *et al.*, 1957b).

Tail feather. The actual length of tail was determined by measuring from the extreme tip of the pygostyle to the end of the longest feather (Hays, 1952).

Breast Feather. One breast feather was plucked from the middle area of the right part of breast area of the chicken and was then measured in mm from the end of quill to the tip of the feather (experiment 1) or one breast feather in the middle of the breast area was measured from the base of the pin feather to the farthest point of emergence.

Back feather. One back feather in the centre of the back at the hip region was measured from the base of the pin feather to the farthest point of emergence.

Feathering score. Back and breast feathering scores were determined by visual assessment of feather cover on the back and breast on a scale where:

1 = No feathers, 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/breast

4 = Most of the sheaths opened

5 = All back/breast area not completely covered by new feathers

6 = Complete cover

Examples of six scores of the feather cover on the back can be seen in Plates 3.1-3.6

III.7. Statistical Analysis

Data were analysed by analysis of variance, using Genstat V statistical packages. Normal F-Tests were performed on the mean squares ratios due to different factors and their interactions.

Plate 3.1. Visual score 1 of back feathers cover

Plate 3.2. Visual score 2 of back feathers cover

Plate 3.3. Visual score 3 of back feathers cover

Plate 3.4. Visual score 4 of back feathers cover

Plate 3.5. Visual score 5 of back feathers cover

Plate 3.6. Visual score 6 of back feathers cover

CHAPTER IV. EXPERIMENT 1:
THE RESPONSE OF FEATHER AND BODY GROWTH
TO SULPHUR AMINO ACIDS INTAKE

IV.1. INTRODUCTION

A large number of reports have been published during the past decade on the subject of sulphur amino acid (SAA) requirements. However, the requirement values published have been quite variable. Some factors contributing the variable results may be the existence of genetic differences in respect to SAA requirements and also due to the problem of wide variability in digestibility values between feedstuffs.

Fast and slow feathering meat chickens have differences in the rate of feathering. Since the major amino acids involved in the synthesis of feather keratin are the sulphur containing amino acids, cystine and methionine, probably there are also differences in SAA requirements for their growth due to differences in feathering. Therefore, this experiment was conducted to investigate the effect of dietary SAA content on feather growth in the fast and slow feathering lines of meat chickens.

It would be preferable to use digestible amino acid values to ensure that amino acids are eaten in the correct ratios. Therefore, for this experiment the percentage digestibility of the amino acids were used to convert the total to available amino acids.

IV.2. MATERIALS AND METHODS

IV.2.1. Experimental Design

The experimental design used was a 2 x 2 x 6 factorial with male and female broilers of the fast and slow feathering lines and six SAA levels. Diets containing six different protein levels were used giving SAA (methionine and cystine) levels ranging from 80 to 100 per cent of the published requirement. Each treatment was replicated three times with seven chickens of each sex per replicate.

IV.2.2. Birds and Management

To start the experiment 252 male and 252 female broiler chicks of the fast and slow feathering lines were used. These chicks were obtained from eggs of second generation parents of the fast and slow feathering lines and were housed on 9th November 1987.

The day old chicks were weighed and randomly allocated to the various dietary treatments in such a way that the body weight ranges were equally distributed among all treatments. Initially the chickens were placed in one of the three rooms to ensure that room effects were kept to a minimum as a result of cold weather in the early brooding period. At ten days old, 28 chicks were removed from each pen to other pens (the same dietary treatment) which were located in two other rooms. So, seven males and seven females were put together in one pen and were replicated

three times.

IV.2.3. Housing

The experiment was conducted in three rooms of a 14 room poultry house used for growing and breeding research. The rooms functioned as treatment replicates. Each room contained 12 floor pens. Each pen had dimensions of 115 x 115 cm. The layout of the rooms is shown in Fig. 4.1.

In each room the ventilation was by means of thermostatically-controlled exhaust fan in the roof, with side wall air inlets. Each room was space heated by four gas brooders. The minimum and maximum temperatures were recorded every morning, using a Minimum-Maximum dry-bulb thermometer. A measurement of temperature and humidity in each pen was recorded every ten days using a Solomat MPM 500 (Solomat Ltd., Devon). A summary of the temperatures is given in Tables 4.1 and 4.2.

One circular tube feeder with a 100 cm circumference (7.1 cm/bird) was located in the middle of the pen. There were two nipple and cup drinkers available in each pen. Water was provided from the mains to small header supply tanks.

Figure 4.1. The layout of the rooms (experiment 1).
F= Fast, S= Slow; 1,2,3,4,5,6= Diet Series; n= 14 birds/pen

Table 4.1. The average temperature of rooms during the experiment

Date	Temperature Minimum (^{o}C)	Maximum (^{o}C)
10 Nov - 19 Nov	27.8	30.3
20 Nov - 29 Nov	24.7	27.0
30 Nov - 9 Dec	18.9	21.1
10 Dec - 19 Dec	18.8	20.9
20 Dec - 29 Dec	19.3	21.5

Table 4.2. The average temperature and humidity of pens

Date	Temperature (^{o}C)	Humidity (%)
21 November	26.4	52.7
1 December	20.4	63.3
11 December	18.1	62.7
21 December	18.8	62.5
31 December	17.6	72.7

IV.2.4. Diets

Birds were fed one of six starter diets (0-20 days of age) and one of six grower diets (21-50 days of age). These diets were obtained by mixing a SAA deficient diet (Starter: CP= 210 g/kg; Grower: CP= 180 g/kg) with an adequate SAA diet (Starter: CP= 270 g/kg; Grower: CP= 240 g/kg) to get the series of six starter and six grower diets.

The proportions mixed of the SAA deficient diet and adequate SAA diet were 100:0; 80:20, 60:40, 40:60, 20:80 and 0:100 for the six diets. The levels of SAA in the series of six diets ranged from 80 to 100 per cent of published requirement. Methionine was deficient in diet 1 and increased to excess in diet 6, but cystine was deficient in all diets. Since methionine can be converted to cystine by poultry, thus the responses are considered to be due to SAA intake. The starter and grower feeds had similar metabolisable energy contents (ME= 12.7 MJ/kg).

The selected amino acid requirements of the meat chickens are shown in Table 4.3. The composition and the analysis of feeds used are shown in Tables 4.4 and 4.5. The protein level of the six series of broiler diets are shown in Table 4.6. Digestible amino acid contents of the six series of diets can be seen in Tables 4.7 and 4.8.

IV.2.5. Recording Procedure

a. Body Weight, Feather Length and Feather Score

On receiving the chicks they were wing banded, and weighed individually using an Oertling HC 22/51 (1-2000 g) balance. Subsequently, every ten days the chickens were weighed individually from 10 to 50 days of age.

Primary and secondary wing feather lengths were recorded at one day of age (i.e. the day after wing banding). Every ten days subsequently from 10 to 50 days of age the measurement of primary, secondary, tail and breast

Table 4.3. Amino acid requirements of the broiler chickens (g/kg)

Essential Amino Acids	Scott (1982)		NRC (1984)		PRC (1986)**		INRA (1987)		Selected Values		% *** Digest. Amino Acids	Req. of Digest. Amino Acids	
	0 - 2 weeks	2 - 6 weeks	0 - 3 weeks	3 - 6 weeks	0 - 4 weeks	4 - 8 weeks	0 - 2 weeks	> 3 weeks	0-20 days	21- 50 days		0-20 days	21-50 days
Arginine	13.2 (5.0)*	11.4 (5.0)	14.4 (6.3)	12.0 (6.0)	12.6 (5.5)	9.5 (5.0)	13.0 (5.7)	9.5 (4.7)	13.0 (5.7)	10.0 (5.0)	88.0	11.4 (5.0)	8.8 (4.4)
Histidine	5.3 (2.0)	4.5 (2.0)	3.5 (1.5)	3.0 (1.5)	5.0 (2.2)	5.0 (2.6)	4.8 (2.1)	3.5 (1.7)	5.0 (2.2)	4.0 (2.0)	86.0	4.3 (1.9)	3.4 (1.7)
Isoleucine	10.6 (4.0)	9.1 (4.0)	8.0 (3.5)	7.0 (3.5)	9.0 (3.9)	8.0 (4.2)	9.5 (4.1)	6.9 (3.4)	8.0 (3.5)	7.0 (3.5)	86.0	6.9 (3.0)	6.0 (3.0)
Leucine	15.9 (6.0)	13.6 (6.0)	13.5 (5.9)	11.8 (5.9)	16.0 (7.0)	13.0 (6.8)	16.8 (7.3)	12.3 (6.1)	16.0 (7.0)	12.0 (6.0)	85.0	13.6 (5.9)	10.2 (5.1)
Lysine	13.2 (5.0)	11.4 (5.0)	12.0 (5.2)	10.0 (5.0)	12.5 (5.4)	10.0 (5.3)	12.0 (5.2)	9.3 (4.6)	12.0 (5.2)	10.0 (5.0)	86.0	10.3 (4.5)	8.6 (4.3)
Methionine	5.3 (2.0)	4.5 (2.0)	5.0 (2.2)	3.8 (1.9)	-	-	5.0 (2.2)	4.1 (2.0)	5.0 (2.2)	4.0 (2.0)	91.0	4.6 (2.0)	3.6 (1.8)
Cystine	4.2 (1.6)	3.6 (1.6)	-	-	-	-	-	-	4.0 (1.7)	3.2 (1.6)	84.0	3.4 (1.5)	2.7 (1.3)
Meth+Cystine	-	-	9.3 (4.0)	7.2 (3.6)	9.2 (4.0)	8.0 (4.2)	9.0 (3.9)	7.5 (3.7)	9.2 (4.0)	7.2 (3.6)	87.0	8.0 (3.5)	6.3 (3.1)
Phenylalanine	8.5 (3.2)	7.3 (3.2)	7.2 (3.1)	6.3 (3.2)	-	-	-	-	-	-	-	-	-
Tyrosine	8.5 (3.2)	7.3 (3.2)	-	-	-	-	-	-	-	-	-	-	-
Phenyl+Tyros.	-	-	13.4 (5.8)	11.7 (5.9)	15.8 (6.9)	14.0 (7.4)	16.0 (7.0)	11.7 (5.9)	16.0 (7.0)	11.8 (5.9)	86.0	13.8 (6.0)	10.1 (5.1)
Threonine	8.5 (3.2)	7.3 (3.2)	8.0 (3.5)	7.4 (3.7)	8.0 (3.5)	6.5 (3.4)	7.2 (3.1)	5.3 (2.6)	7.0 (3.2)	5.2 (2.6)	83.0	5.8 (2.5)	4.3 (2.2)
Tryptophan	2.4 (0.9)	2.0 (0.9)	2.3 (1.0)	1.8 (0.9)	2.3 (1.0)	1.9 (1.0)	2.2 (1.0)	1.8 (0.9)	2.3 (1.0)	1.6 (0.8)	87.0	2.0 (0.9)	1.4 (0.7)
Valine	8.5 (3.2)	7.3 (3.2)	8.2 (3.6)	7.2 (3.6)	10.0 (4.3)	9.0 (4.7)	10.4 (4.5)	6.1 (3.0)	10.0 (4.3)	6.4 (3.2)	84.0	8.4 (3.7)	5.4 (2.7)
Crude Protein	265.0	224.0	230.0	200.0	230.0	190.0	230.0	201.0	230.0	200.0	-	230.0	200.0

* Values in the brackets are amino acids requirement as percentage of protein

** As cited by Bolton and Blair (1986)

*** Calculation based on the data of Gous and Morris (1985)

(.....continued)

Table 4.3. (continued)

*** Percentage of digestible amino acid requirement was calculated as:

$$Y = \frac{b}{a} \times 100\%$$

where Y = Percentage of digestible amino acid requirement from total amino acid requirement

a = Total amino acid in the diets (g/kg) [base on recalculation of experimental diet of Gous and Morris (1985)]

b = Digestible amino acid in the diets (g/kg) [base on recalculation of experimental diet of Gous and Morris (1985) using table digestible amino acids of feedstuffs (Janssen *et al.*, 1979)]

Example:

Methionine : a = 10.51 g/kg
b = 9.55 g/kg
Y = 90.9 %

Table 4.4. Composition of experimental basal diets (kg)

Ingredients	Starter		Grower	
	Diet 1	Diet 6	Diet 1	Diet 6
Maize (10.7)*	112.0	-	440.0	-
Wheat (9.0)	600.0	403.0	214.0	554.0
Soyabean meal (45)	60.0	371.0	53.0	214.0
Meat&Bone meal (50/1)	50.0	40.0	120.0	62.0
Fish meal, white (61)	68.5	-	2.0	22.0
FF soya (38)	100.0	100.0	52.0	100.0
Wheatfeed (15.7)	-	-	100.0	-
Dicalcium phosphate	-	10.0	-	-
Limestone	2.5	9.0	-	6.0
Salt	-	2.0	0.5	0.5
Lysine supplement	0.5	-	2.2	-
Methionine supplement	-	3.0	0.2	1.5
Maize oil	1.0	56.5	10.6	34.5
Vitamin & mineral mix**	5.0	5.0	5.0	5.0
Coccidiostat	0.5	0.5	0.5	0.5
Total	1,000.0	1,000.0	1,000.0	1,000.0

* Values in parentheses are the assumed percentage crude protein in the ingredients, and the protein and fat content of meat and bone meal (50/1).

** Vitamin and mineral mix provides per kilogram of diet: vitamin A, 14,480 IU; vitamin D3, 5,400 IU; vitamin E, 35 IU; Biotin, 150 ug; copper, 15 mg, selenium, 0.2 mg; molybdenum, 1.5 mg.

Starter Diets:

	Starter Diet 1	Starter Diet 6
Diet 1 =	100%	0%
Diet 2 =	80%	20%
Diet 3 =	60%	40%
Diet 4 =	40%	60%
Diet 5 =	20%	80%
Diet 6 =	0%	100%

Grower Diets:

	Grower Diet 1	Grower Diet 6
Diet 1 =	100%	0%
Diet 2 =	80%	20%
Diet 3 =	60%	40%
Diet 4 =	40%	60%
Diet 5 =	20%	80%
Diet 6 =	0%	100%

Table 4.5. Calculated and chemical analysis of experimental diets

	Starter		Grower	
	Diet 1	Diet 6	Diet 1	Diet 6
Calculated Analysis :				
- Metabolisable Energy (MJ/kg)	12.7	12.7	12.7	12.7
- Crude Protein (g/kg)	210.0	270.0	180.0	240.0
- Digest. Methionine (g/kg)	3.2	6.1	2.4	4.5
- Digest. Cystine (g/kg)	2.6	3.4	2.2	3.0
- Digest. Methionine+Cystine (g/kg)	5.8	9.4	4.6	7.5
- Calcium (g/kg)	17.0	14.7	20.1	17.3
- Av. Phosphorus (g/kg)	9.9	8.6	11.2	9.7
- Ether Extract (g/kg)	27.6	78.9	36.5	57.5
- Crude Fibre (g/kg)	25.7	26.9	28.6	26.7
Chemical Analysis :				
- Dry Matter (g/kg)	879.0	874.0	874.0	872.0
- Crude Protein (g/kg)	208.0	262.0	184.0	232.0
- Calcium (g/kg)	15.2	16.8	20.2	15.7
- Phosphorus (g/kg)	10.3	10.0	13.3	10.3
- Ether Extract (g/kg)	53.8	95.8	54.0	69.3

Table 4.6. Protein level of the six series of diets calculated from the four determined values (g/kg)

Diets	Period I (0 - 20 Days of Age)	Period II (21 - 50 Days of Age)
1	208	184
2	219	194
3	230	203
4	240	213
5	251	222
6	262	232

Table 4.7. Digestible amino acid contents (g/kg) of the diets for period I (0-20 days of age)

Essential Amino Acids	Diets 1	2	3	4	5	6
Arginine	10.5 (1.01)*	11.4 (1.03)	12.5 (1.08)	13.4 (1.12)	14.4 (1.14)	15.3 (1.17)
Histidine	4.0 (1.00)	4.2 (1.00)	4.5 (1.02)	4.7 (1.02)	5.0 (1.04)	5.2 (1.04)
Isoleucine	7.2 (1.16)	7.7 (1.15)	8.4 (1.22)	8.9 (1.24)	9.6 (1.28)	10.1 (1.28)
Leucine	12.6 (1.02)	13.3 (1.02)	14.0 (1.03)	14.6 (1.03)	15.3 (1.03)	16.0 (1.03)
Lysine	11.3 (1.00)	11.9 (1.00)	12.7 (1.01)	13.4 (1.03)	14.2 (1.04)	14.8 (1.05)
Methionine	3.2 (0.76)	3.8 (0.86)	4.4 (0.96)	4.8 (1.00)	5.4 (1.08)	5.9 (1.13)
Cystine	2.6 (0.84)	2.8 (0.85)	2.9 (0.85)	3.0 (0.86)	3.1 (0.84)	3.3 (0.85)
Meth + Cystine	5.8 (0.81)	6.6 (0.87)	7.3 (0.91)	7.8 (0.94)	8.5 (0.98)	9.2 (1.01)
Tyros + Phenyl	12.9 (1.03)	13.7 (1.07)	14.9 (1.08)	15.7 (1.09)	16.9 (1.12)	17.8 (1.13)
Threonine	5.7 (1.10)	6.1 (1.00)	6.7 (1.16)	7.1 (1.18)	7.7 (1.22)	8.1 (1.23)
Tryptophan	1.9 (1.00)	2.1 (1.05)	2.2 (1.05)	2.3 (1.05)	2.4 (1.04)	2.6 (1.08)
Valine	8.0 (1.03)	8.5 (1.04)	8.9 (1.05)	9.4 (1.06)	9.9 (1.06)	10.3 (1.06)

* Values in the brackets are digestible amino acid contents expressed as multiples of the requirements of starting broilers

Table 4.8. Digestible amino acid contents (g/kg) of the diets for period II (21-50 Days of age)

Essential Amino Acids	Diets 1	2	3	4	5	6
Arginine	9.7 (1.20)*	10.4 (1.22)	10.9 (1.22)	11.6 (1.23)	12.2 (1.24)	12.9 (1.26)
Histidine	3.1 (1.00)	3.4 (1.00)	3.7 (1.06)	3.8 (1.06)	4.1 (1.08)	4.3 (1.10)
Isoleucine	5.5 (1.00)	6.0 (1.03)	6.6 (1.08)	7.1 (1.11)	7.7 (1.15)	8.3 (1.19)
Leucine	11.3 (1.20)	11.7 (1.18)	12.2 (1.17)	12.8 (1.17)	13.2 (1.17)	13.7 (1.16)
Lysine	7.9 (1.00)	8.4 (1.01)	8.7 (1.00)	9.2 (1.00)	9.8 (1.03)	10.2 (1.02)
Methionine	2.4 (0.73)	2.8 (0.80)	3.1 (0.84)	3.6 (0.95)	4.0 (1.00)	4.4 (1.05)
Cystine	2.2 (0.92)	2.4 (0.96)	2.5 (0.96)	2.6 (0.93)	2.7 (0.93)	2.9 (0.97)
Meth + Cystine	4.6 (0.81)	5.2 (0.87)	5.6 (0.89)	6.2 (0.94)	6.7 (0.97)	7.3 (1.01)
Tyros + Phenyl	10.5 (1.12)	11.3 (1.14)	12.3 (1.18)	13.1 (1.20)	13.9 (1.23)	14.8 (1.25)
Threonine	4.5 (1.13)	4.9 (1.14)	5.4 (1.20)	5.8 (1.23)	6.2 (1.27)	6.7 (1.31)
Tryptophan	1.3 (1.00)	1.5 (1.07)	1.7 (1.21)	1.8 (1.20)	1.9 (1.19)	2.1 (1.31)
Valine	6.4 (1.28)	6.9 (1.33)	7.4 (1.35)	7.9 (1.36)	8.3 (1.38)	8.8 (1.40)

* Values in the brackets are digestible amino acid contents expressed as multiples of the requirements of growing broilers

feathers, and feathering score of breast and back feathers was carried out. The methods of feather measurements and feathering score can be seen in Chapter III.

b. Feed Intake

Six kilograms of each diet was weighed and put into plastic bags. Thus, the feed had been prepared before the feed in the tube feeder was all consumed. Every ten days, the feed remaining in the tube feeder was weighed. Therefore, the difference between the feed given and feed remaining was assumed to be feed intake. The feed intakes per bird were calculated every ten days, on a pen basis taking into account the number of chickens alive at the beginning and end of the period.

IV.3. RESULTS

The results of experiment 1 from 1 to 50 days of age are summarised in Appendices 1-5. To demonstrate relationships between the amount of SAA intake and body weight and feather length at 50 days of age, quadratic regression equations were calculated. Since the scores of breast and back feathers were not different between lines, the regression equations were not calculated. These equations are presented in Table 4.9. The value of coefficient of determination (R^2) in the equations show the percentage variation in Y (body weight or feather lengths) that is attributed to variation in X (SAA intake).

Table 4.9. Quadratic regression equations of body weight, feather length and feather score.

Line	Regression Equation	R^2 (%)
Fast	BWT = - 2054 + 271 SAA - 4.53 SAA^2	94.6
	PFL = 127 + 0.72 SAA - 0.0069 SAA^2	35.8
	SFL = 92.7 + 3.12 SAA - 0.0483 SAA^2	71.3
	TFL = 58.5 + 2.78 SAA - 0.0283 SAA^2	75.6
	BFL = 42.1 + 1.82 SAA - 0.0261 SAA^2	47.3
Slow	BWT = - 22 + 103 SAA - 1.35 SAA^2	91.3
	PFL = 107 + 1.91 SAA - 0.0239 SAA^2	62.8
	SFL = 57.9 + 4.71 SAA - 0.0701 SAA^2	50.8
	TFL = - 54.4 + 7.40 SAA - 0.103 SAA^2	69.5
	BFL = 7.4 + 4.06 SAA - 0.0622 SAA^2	67.0

SAA= sulphur amino acid intake (g/b); BWT= body weight; PFL= primary feather length; SFL= secondary feather length; TFL= tail feather length; BFL= breast feather length

Since males and females were raised together in the same pen, therefore these equations were based on the average of body weights and feather lengths of males and females. Those equations show allow the prediction of the maximum response in body weight and feather lengths due to SAA intake. However, the response of the various feathers to SAA intake is variable, in the fast feathering line in particular. The tail feathers in both lines show the largest R^2 (Table 4.9).

The asymptote predicts that a maximum body weight of 2000 g and 1976 g results from the consumption of 30.0 and 35.4 g SAA for fast and slow lines, respectively during 50 days of their life. While maximum feather lengths of primary, secondary and tail feathers were reached as a result of the consumption of 32.7 and 35.4 g SAA for fast and slow lines, respectively. For example, the graphs of growth response in body weight and feather lengths of primary, secondary and tail feathers to SAA intake are shown in Figs. 4.2, 4.3, 4.4 and 4.5. It seems that the slow feathering birds needed more SAA for maximum body and feather growth than the fast feathering birds.

IV.3.1. Feed Intake, Sulphur Amino Acid Intake and Feed Conversion Ratio

In order to determine if there was a difference in the performance of the birds during two growth phases, the results of cumulative feed intake, cumulative SAA intake and feed conversion ratio (FCR) are presented in two periods, period I (0-20 days of age) and period II (21-50 days of age). Furthermore, the results of body weight and feathering are shown at 1, 20 and 50 days of age.

During period 0-20 days of age and 21-50 days of age, the effects of line and diet on cumulative feed intake, cumulative SAA intake and FCR were significant ($P<0.001$). However, there was no interaction between the effects of line and diet in both periods (Tables 4.10 and 4.11).

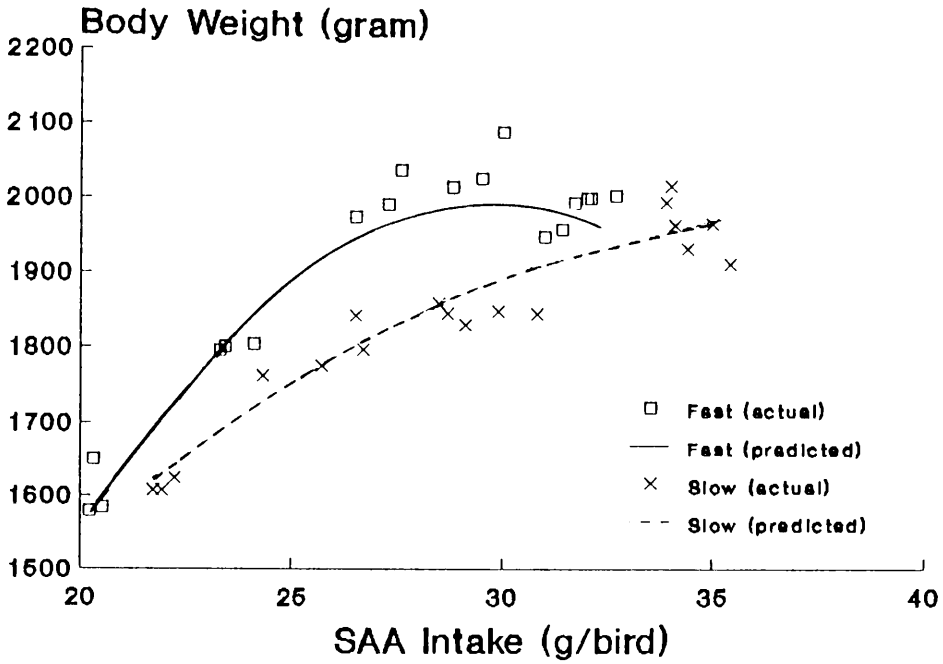


Figure 4.2. The predicted and actual body weight response to sulphur amino acids (SAA) intake at 50 days of age

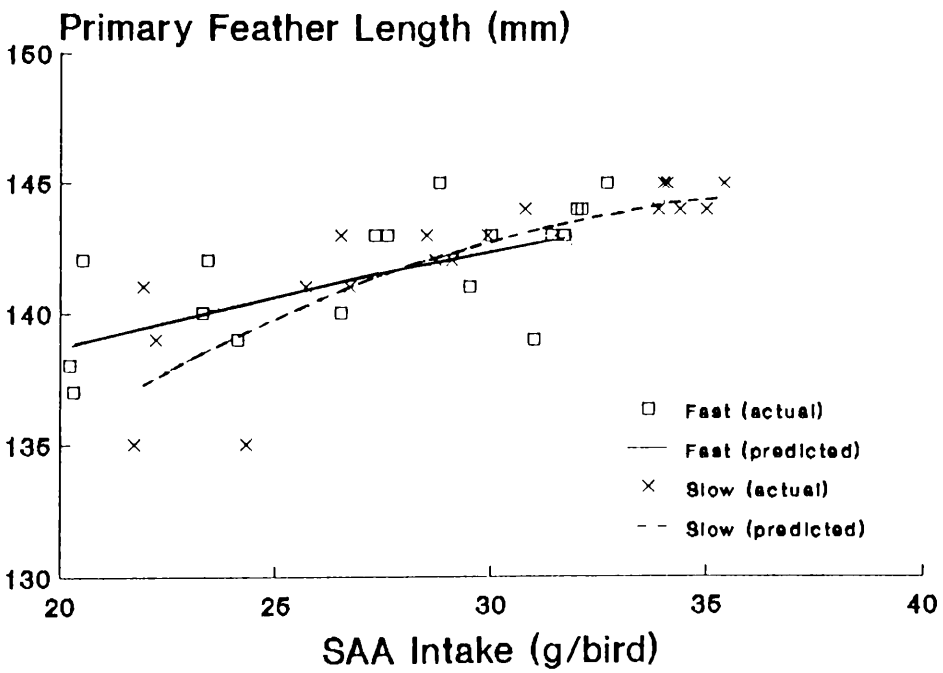


Figure 4.3. The predicted and actual primary feather length response to sulphur amino acids (SAA) intake at 50 days of age

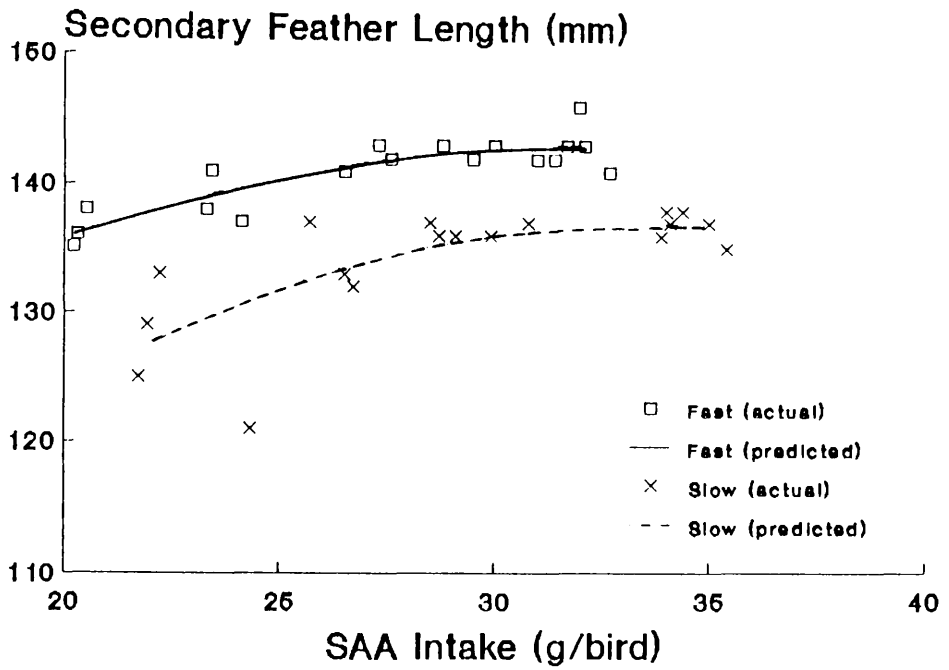


Figure 4.4. The predicted and actual secondary feather length response to sulphur amino acids (SAA) intake at 50 days of age

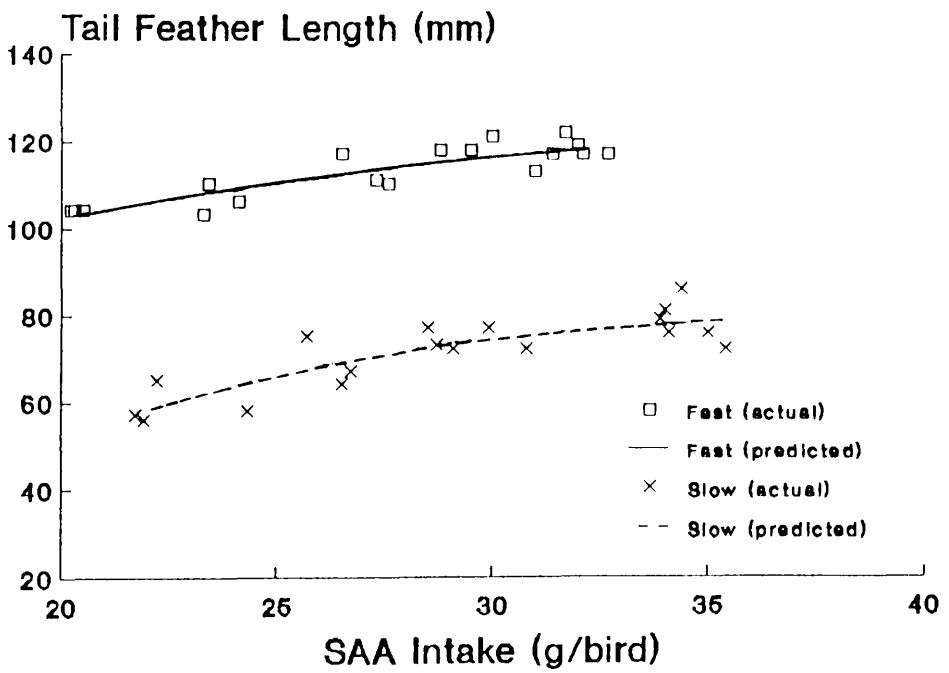


Figure 4.5. The predicted and actual tail feather length response to sulphur amino acids (SAA) intake at 50 days of age

Table 4.10. Effects of line and diet on feed intake, sulphur amino acid intake, feed conversion ratio and body weight gain during period I (0-20 days of age)

Line	Diet	Cumulative Feed Intake (g/b/d)	Cumulative SAA Intake (mg/b/d)	FCR [1)]	Body Weight Gain g/b/d)
Fast	1	38.1	220.8	1.90	20.1
	2	38.4	253.2	1.84	20.9
	3	42.5	310.5	1.79	23.7
	4	41.4	323.5	1.71	24.2
	5	40.8	346.8	1.73	23.6
	6	37.3	343.2	1.66	22.5
Slow	1	39.9	231.3	2.04	19.6
	2	41.0	270.3	1.92	21.3
	3	43.2	314.8	1.87	23.0
	4	42.1	327.8	1.81	23.3
	5	42.6	361.7	1.80	23.7
	6	38.5	354.3	1.64	23.4
SED		1.10	8.54	0.04	0.34
MAIN EFFECTS					
Line - Fast		39.8	299.7	1.77	22.5
- Slow		41.2	310.1	1.85	22.4
SED		0.45	3.49	0.02	0.14
Diet - 1		39.0	226.1	1.97	19.8
2		39.7	261.8	1.88	21.1
3		42.9	312.7	1.83	23.4
4		41.8	325.7	1.76	23.7
5		41.7	354.3	1.76	23.6
6		37.9	348.8	1.65	23.0
SED		0.78	3.49	0.03	0.24
Significance of Differences:					
Line (L)		**	**	***	NS
Diet (D)		***	***	***	***
L x D		NS	NS	NS	**

1) FCR = Feed Conversion Ratio
= g feed/g body weight gain

* = P < 0.05; ** = P < 0.01; *** = P < 0.001
NS = Non Significant

Table 4.11. Effects of line and diet on feed intake, sulphur amino acid intake, feed conversion ratio and body weight gain during period II (21-50 days of age)

Line	Diet	Cumulative Feed Intake (g/b/d)	Cumulative SAA Intake (mg/b/d)	FCR [1)]	Body Weight Gain (g/b/d)
Fast	1	115.3	530.1	2.98	38.7
	2	118.6	616.8	2.66	44.7
	3	124.7	698.1	2.52	49.5
	4	123.5	765.5	2.45	50.5
	5	124.8	836.0	2.54	49.1
	6	112.8	823.4	2.25	50.2
Slow	1	125.3	576.7	3.18	39.4
	2	129.2	671.8	2.95	43.8
	3	129.4	724.8	2.86	45.3
	4	125.0	775.0	2.79	44.8
	5	137.9	923.8	2.90	47.6
	6	122.7	895.3	2.47	49.6
SED		3.13	18.10	0.07	0.69
MAIN EFFECTS					
Line - Fast		119.9	711.7	2.57	47.1
Slow		128.3	761.2	2.86	45.1
SED		1.28	7.39	0.03	0.28
Diet - 1		120.3	553.4	3.08	39.0
2		123.9	644.3	2.80	44.2
3		127.1	711.5	2.69	47.4
4		124.3	770.3	2.62	47.6
5		131.3	879.9	2.72	48.4
6		117.7	859.4	2.36	49.9
SED		2.21	12.8	0.05	0.49
Significance of Differences:					
Line (L)		***	***	***	***
Diet (D)		***	***	***	***
L x D		NS	NS	NS	***

1) FCR = Feed Conversion Ratio
= g feed/g body weight gain

* = $P < 0.05$; ** = $P < 0.01$; *** = $P < 0.001$
NS = Non Significant

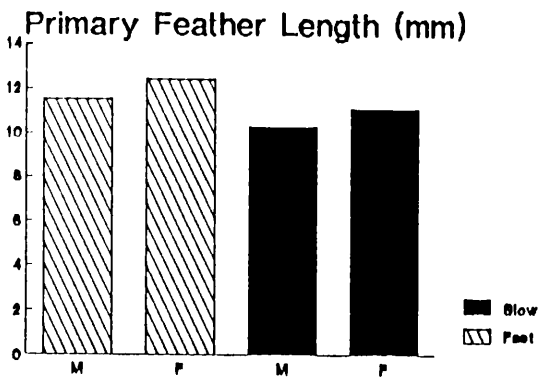
Birds of the fast and slow feathering lines fed diet 5 had more SAA intake and those fed diet 6 had a better FCR than those birds fed the other diets. The lowest SAA intake and the poorest FCR was on diet 1. FCR of the fast and slow feathering lines showed an improvement as the SAA level increased.

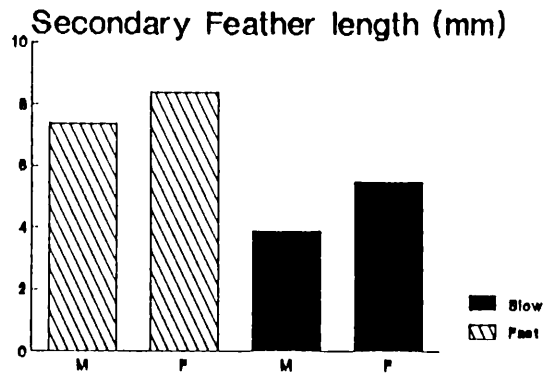
IV.3.2. Body Weight and Feather Lengths

At hatching day, chicks of the fast feathering line tended to have a heavier mean body weight and longer primary and secondary feathers than the slow feathering line. Males had a greater body weight than females, but females had longer primary and secondary feathers than males (Fig.4.6). Primary and secondary feathers of fast and slow feathering lines at hatching day are shown in Plates 4.1-4.4.

At 20 days of age, the effects of line, sex and diet were found to be significant for body weight and feather lengths and scores (Table 4.12). But, at 50 days of age, the significant differences existed only for body weight and lengths of secondary and tail feathers. Also there was an effect of line and diet on tail feather length and an effect of diet on breast feather length (Table 4.13)

There were no line x sex interactions on all feathers measured, except for breast feather length at 20 days of age. But at 50 days of age body weight and lengths of primary and secondary feathers showed a line x sex interaction. However, only the body weight data showed a





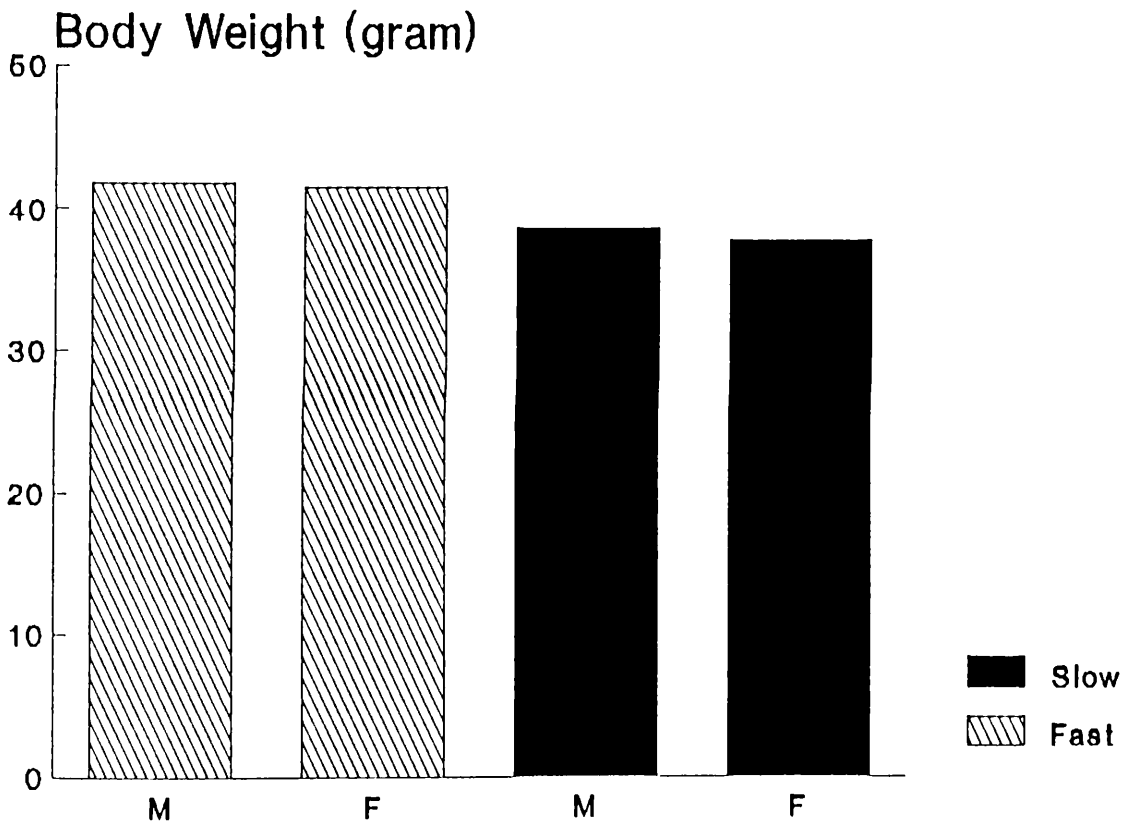


Figure 4.6. The average of body weight and the lengths of primary and secondary feathers at one day old

Plate 4.1. Primary wing feathers of a typical fast feathering female at hatching day

Plate 4.2. Primary wing feathers of a typical fast feathering male at hatching day

Plate 4.3. Primary wing feathers of a typical slow feathering female at hatching day

Plate 4.4. Primary wing feathers of a typical slow feathering male at hatching day

Table 4.12. Effects of age, line and sex on live body weight, feather Lengths and feather scores at 20 days of age

Line/ Sex	Diet	Live Body Weight (gram)	Primary Feather Length (mm)	Secondary Feather Length (mm)	Tail Feather Length (mm)	Breast Feather Length (mm)	Breast Feather Score	Back Feather Score
FF	1	427.7	81.4	67.4	27.7	28.3	6.0	3.7
	2	440.4	83.6	69.7	28.5	31.4	6.0	3.9
	3	497.0	85.4	71.1	31.7	33.6	6.0	4.8
	4	497.1	87.2	75.3	34.3	33.8	6.0	5.0
	5	481.3	85.4	73.2	34.1	35.7	6.0	4.7
	6	474.6	85.4	72.8	33.8	37.5	6.0	4.7
FM	1	457.8	78.4	58.2	16.0	28.7	5.8	3.2
	2	480.0	79.9	61.6	18.6	32.3	6.0	3.4
	3	537.5	83.0	65.3	19.2	32.9	6.0	4.1
	4	555.3	85.7	68.4	21.4	33.2	6.0	4.7
	5	547.6	82.9	66.3	19.5	34.3	6.0	4.2
	6	510.5	81.9	64.6	19.0	35.1	6.0	3.8
SF	1	408.9	69.2	46.7	10.3	20.1	4.4	2.1
	2	440.4	70.8	49.1	12.6	22.0	4.4	2.4
	3	469.2	71.0	49.2	13.2	25.4	5.4	3.1
	4	481.3	73.2	50.7	14.3	27.7	5.6	3.5
	5	480.7	73.2	55.0	17.3	30.9	5.7	3.7
	6	487.6	77.0	57.5	16.2	30.1	5.8	3.9
SM	1	451.0	60.5	37.1	6.4	14.6	3.0	1.4
	2	489.1	62.0	40.6	7.5	23.1	4.5	1.8
	3	525.4	64.6	40.7	7.8	23.3	4.8	2.0
	4	526.4	64.7	40.8	8.0	23.5	5.0	2.1
	5	542.2	67.6	44.5	9.3	26.0	5.3	2.1
	6	525.2	64.7	38.8	8.1	23.6	4.7	2.1
SED		8.44	2.34	2.62	2.10	2.99	0.32	0.41

FF= Fast Female; FM= Fast Male; SF= Slow Female; SM= Slow Male

(.....continued)

Table 4.12. (continued)

	Live Body Weight (gram)	Primary Feather Length (mm)	Secondary Feather Length (mm)	Tail Feather Length (mm)	Breast Feather Length (mm)	Breast Feather Score	Back Feather Score
MAIN EFFECTS							
Line - Fast	492.2	83.4	67.8	25.3	33.1	6.0	4.2
Slow	485.6	68.2	45.9	10.9	24.2	4.9	2.5
SED	2.44	0.67	0.76	0.61	0.86	0.09	0.12
Sex - Male	512.3	73.0	52.2	13.4	27.5	5.2	2.9
Female	465.5	78.6	61.5	22.8	29.7	5.6	3.8
SED	2.44	0.67	0.76	0.61	0.86	0.09	0.12
Diet - 1	436.4	72.4	52.4	15.1	22.9	4.8	2.6
2	462.4	74.1	55.2	16.8	27.2	5.2	2.9
3	507.3	76.0	56.6	18.0	28.8	5.5	3.5
4	515.0	77.7	58.8	19.5	29.5	5.6	3.8
5	512.9	77.3	59.8	20.1	31.7	5.7	3.7
6	499.5	77.2	58.4	19.3	31.6	5.6	3.6
SED	4.22	1.17	1.31	1.05	1.50	0.16	0.20
Significance of Differences:							
Line (L)	**	***	***	***	***	***	***
Sex (S)	***	***	***	***	*	***	***
Diet (D)	***	***	***	***	***	***	***
L x S	NS	***	*	***	NS	**	**
L x D	***	NS	NS	NS	NS	***	NS
S x D	*	NS	NS	NS	NS	NS	NS
L x S x D	NS	NS	NS	NS	NS	NS	NS

NS = Non Significant; * = P < 0.05 ; ** = P < 0.01 ; *** = P < 0.001

Table 4.13. Effects of age, line and sex on live body weight, feather lengths and feather scores at 50 days of age

Line/ Sex	Diet	Live Body Weight (gram)	Primary Feather Length (mm)	Secondary Feather Length (mm)	Tail Feather Length (mm)	Breast Feather Length (mm)	Breast Feather Score	Back Feather Score
FF	1	1420.4	135.1	131.8	118.9	67.9	6.0	6.0
	2	1647.7	136.1	134.4	119.6	69.1	6.0	6.0
	3	1862.1	137.9	138.1	124.6	73.0	6.0	6.0
	4	1844.1	138.8	138.2	129.0	70.0	6.0	6.0
	5	1773.8	140.3	138.3	126.9	73.8	6.0	6.0
	6	1773.5	139.5	138.6	127.2	75.9	6.0	6.0
FM	1	1785.4	143.4	140.6	88.9	69.4	6.0	6.0
	2	1952.5	144.3	143.1	93.6	70.6	6.0	6.0
	3	2140.5	146.6	145.6	99.8	75.5	6.0	6.0
	4	2236.7	147.0	146.9	108.8	73.3	6.0	6.0
	5	2204.5	147.5	147.5	108.0	72.9	6.0	6.0
	6	2190.4	144.4	146.9	107.4	72.8	6.0	6.0
SF	1	1421.2	136.6	130.8	70.8	67.1	6.0	6.0
	2	1635.4	137.9	133.5	75.3	70.8	6.0	6.0
	3	1747.6	139.4	135.7	82.8	72.7	6.0	6.0
	4	1752.8	140.5	135.9	85.9	73.5	6.0	6.0
	5	1745.7	140.8	136.2	91.9	73.7	6.0	6.0
	6	1805.5	143.2	140.6	99.7	75.7	6.0	6.0
SM	1	1803.1	140.0	126.9	47.9	65.7	6.0	5.9
	2	1920.7	140.3	126.8	57.8	69.0	6.0	5.9
	3	1941.6	145.4	135.1	59.3	71.6	6.0	6.0
	4	1942.5	145.5	136.4	62.0	72.2	6.0	6.0
	5	2131.8	148.0	137.5	64.4	72.2	6.0	6.0
	6	2182.6	146.3	133.0	58.0	72.1	6.0	5.9
SED		29.85	2.22	3.15	4.65	2.55	0.0	0.03

FF= Fast Female; FM= Fast Male; SF= Slow Female; SM= Slow Male

(.....continued)

Table 4.13. (continued)

	Live Body Weight (gram)	Primary Feather Length (mm)	Secondary Feather Length (mm)	Tail Feather Length (mm)	Breast Feather Length (mm)	Breast Feather Score	Back Feather Score
MAIN EFFECTS							
Line - Fast	1902.6	141.7	140.8	112.7	72.0	6.0	6.0
Slow	1835.9	142.0	134.0	71.3	71.4	6.0	6.0
SED	8.62	0.64	0.91	1.34	0.74	0.00	0.00
Sex - Male	2036.0	144.9	138.9	79.7	71.5	6.0	6.0
Female	1702.5	138.8	136.0	104.4	71.9	6.0	6.0
SED	8.62	0.64	0.91	1.34	0.74	0.00	0.00
Diet - 1	1607.5	138.7	132.5	81.6	67.6	6.0	6.0
2	1789.1	139.6	134.4	86.6	69.9	6.0	6.0
3	1922.9	142.3	138.6	91.6	73.2	6.0	6.0
4	1944.0	143.0	139.4	96.4	72.2	6.0	6.0
5	1963.9	144.1	139.9	97.8	73.2	6.0	6.0
6	1988.0	143.3	139.8	98.1	74.1	6.0	6.0
SED	14.93	1.11	1.58	2.32	1.27	0.00	0.00
Significance of Differences:							
Line (L)	***	NS	***	***	NS	NS	NS
Sex (S)	***	***	***	***	NS	NS	NS
Diet (D)	***	***	***	***	***	NS	NS
L x S	***	*	***	NS	NS	NS	NS
L x D	***	NS	NS	NS	NS	NS	NS
S x D	***	NS	NS	NS	NS	NS	NS
L x S x D	*	NS	NS	*	NS	NS	NS

NS = Non Significant; * = P < 0.05 ; ** = P < 0.01 ; *** = P < 0.001

line x diet and sex x diet interaction at both ages.

The differences in body weight between the fast and slow feathering lines at 20 and 50 days of age were variable. But males were always heavier than females in both lines.

The fast feathering line had longer primary, secondary, tail and breast feathers and higher breast and back feather scores than slow feathering line at 20 days of age. At this age, females had longer feathers and higher scores than males.

However, at 50 days of age, there were no significant differences on primary feather length, breast feather length and breast and back feather scores between both lines. Males had longer primary (fast and slow lines) and secondary (fast line) feathers than females. But, females still had longer secondary (slow line) and tail (fast and slow lines) feathers than males. There were no significant differences on breast feather length and feather scores between males and females in both lines.

The diets which gave the maximum response in body weight and feathering are shown in Table 4.14.

At 20 days of age, the birds of the fast feathering line fed diet 4 were heavier and longer primary, secondary and tail feathers, and those fed diet 6 had longer breast feathers than those fed the other diets. In the slow feathering line the males fed diet 5 and females fed diet 6 were heavier, had longer feathers and higher breast feather scores than those birds fed other diets. However, there were

Table 4.14. Diets giving maximum response in body weight, feather lengths and feather scores (see material and methods for description of diets)

Line	Fast				Slow			
Age (days)	20		50		20		50	
Sex	M	F	M	F	M	F	M	F
* Body Weight	4	3	4	3	5	6	6	6
* Feather Type:								
- Primary	4	4	5	5	5	6	5	6
- Secondary	4	4	5	6	5	6	5	6
- Tail	4	4	4	4	5	5	5	6
- Breast	6	6	3	6	5	5	4	6
- Breast Score	1	1	1	1	5	6	1	1
- Back Score	4	4	1	1	4	6	1	1

M= Male; F= Female

no effects of diet on breast feather score in the fast feathering line. The fast feathering females and males and the slow feathering males fed diet 4 had higher back feather scores than those birds fed other diets. But, the slow feathering females which had the highest back feather score were those fed diet 6.

At 50 days of age, body weight was found to be the heaviest in the fast feathering females fed diet 3, fast feathering males fed diet 4 and slow feathering birds (both sexes) fed diet 6. The fast feathering line fed diet 4 and 5 had longer tail and primary feathers, respectively. The fast feathering line fed diet 5 (male) or 6 (female) and 3 (male) or 6 (female) had longer secondary and breast feathers, respectively. Primary, secondary, tail and breast feather lengths were found to be longer in the slow feathering females fed diet 6. The slow feathering males fed diet 5 had longer primary, secondary and tail feathers, and those birds fed diet 4 had longer breast feathers. However, there were no differences among feather scores due to the diets

IV.4. DISCUSSION

The sulphur containing amino acids are quantitatively the most important for feather growth, since they are the dominant amino acids in feather keratin. Therefore accurate determinations of the SAA requirements during various stages of growth are necessary to ensure proper diet formulation for birds with variability in feather growth.

In this experiment, SAA were deficient in diet 1 and increased to adequacy in diet 6, with a deficiency of methionine in diet 1 and excess methionine in diet 6, but a deficiency of cystine in all diets. The methionine/cystine ratio varied from approximately 1.23 to 1.79 for the starter diets (CP= 208 to 262 g/kg) and from 1.09 to 1.52 for the grower diets (CP= 184 to 232 g/kg). Since methionine can be converted to cystine by poultry, the responses were considered to be due to SAA intake.

Quadratic equations were used to identify the SAA intake giving maximum response. Other equations and models may used to study responses for quasi-economic purposes but their use seems unjustified to study the differences between lines.

Generally, maximum responses in body weight and feather lengths due to SAA intake were observed. An unexpected result was that the slow feathering line responded to a higher SAA intake than the fast feathering line for body weight and feather growth during the 50 days of their life. It seems that chickens of the fast feathering line were more efficient in using SAA for their growth than those of the slow feathering line.

The discussion of the results will be more specific about feed intake, SAA intake, feed conversion ratio (FCR), body weight and feather growth, as affected by SAA level in the diets for males and females of the fast and slow feathering lines during the periods I (0-20 days of age) and period II (21-50 days of age). Furthermore to remove the

effect of body weight and thus allow independent differences between line and sex on feather growth to be observed the ratio of feather length to body weight was calculated; this will also be discussed.

IV.4.1. Feed Intake, Sulphur Amino Acids Intake and Feed Conversion Ratio

Diet 1 with 5.9 g SAA/kg (208 g CP/kg) during period I and 4.7 g SAA/kg (184 g CP/kg) during period II, when fed to the chickens decreased feed intake and SAA intake. The deficient SAA diet was also associated with a poorer FCR. This result is in agreement with Solberg *et al.* (1971) and Booth (1979) who reported that a severe methionine deficiency caused a decrease in feed intake. Combs (1962) and Summers (1974) reported that as the protein level of a ration decreased there is a tendency for intake to increase. However, in this study, the protein level in the diet 1 was low, but feed intake was decreased, and may be attributed to the severe deficiency of SAA.

The feed intake on diet 5 was higher than that on diet 6, whereas SAA intake on diet 5 was not different to that on diet 6. Diet 5 contained 8.6 g SAA/kg (251 g CP/kg) during period I and 6.8 g SAA/kg (222 g CP/kg) during period II. The chickens on this diet were consuming more feed to try to make up the SAA deficiency of the diet. In this case, the increase in feed intake of diet 5 was due to the slight deficiency of SAA. This result is in agreement with Solberg

et al. (1971), Boorman (1974) and Summers (1974) who reported that moderate deficiencies of amino acids cause an increased feed intake either in response to changes in the energy metabolism or in response to the increased demand for the deficient amino acid.

The slow feathering line had a greater cumulative feed intake and SAA intake and slower growth than the fast feathering line. It is reasonable to conclude that the fast feathering line had a better utilisation of SAA.

During period I, FCR of the chickens showed an improvement as the SAA level increased from 5.8 g/kg (208 g CP/kg) to 9.2 g SAA/kg (260 g CP/kg) of diet. The improvement in FCR was 0.094 for each g/kg increase in SAA content. During period II, the rule was similar to period I. But, the chickens fed diet 5 (6.7 g SAA/kg) had a slightly higher FCR than chickens fed diet 6 (7.3 g SAA/kg). However, the improvement in FCR was 0.267 for each g/kg increase in SAA content. In both the fast and slow lines the FCR was best at the highest SAA level. This result is in agreement with Nelson *et al.* (1960) and Combs (1964) who reported that FCR of the chickens showed an improvement as the SAA level increased.

IV.4.2. Body Weight

The slow feathering line showed more response to the higher SAA diet than the fast feathering line, since the slow feathering line fed the highest SAA diet (period I=9.2

g SAA/kg; period II= 7.3 g SAA/kg) had the heaviest body weight. In contrast the fast feathering line achieved maximum body weight with 7.8 g SAA/kg (period I) and 6.2 g SAA/kg (period II) in the diets. In this case, apparently the slow feathering line required a higher SAA than the fast feathering line for maximum growth.

IV.4.3. Feather Lengths

The fast feathering line had longer feathers than the slow feathering line for all feathers measured at 20 days of age. In the first period the females had longer feathers and higher scores than males, but in the second period males had longer primary feathers than females.

At 20 days of age, the fast feathering line required a higher SAA content for maximum breast feather length (9.2 g SAA/kg) than those for the other feathers (7.8 g SAA/kg). While the slow feathering line required a higher SAA content (8.5 g SAA/kg) than the fast feathering line (7.8 g SAA/kg) for maximum feather lengths, except for breast feather length.

At 50 days of age, the difference between lines in feathering was shown only in the secondary and tail feathers which in the fast feathering line were longer than those feathers in the slow feathering line. There were no line x diet interactions in those feathers measured. However, the females of slow feathering line had a higher SAA requirement (7.3 g SAA/kg= diet 6) than males (6.7 g SAA/kg=

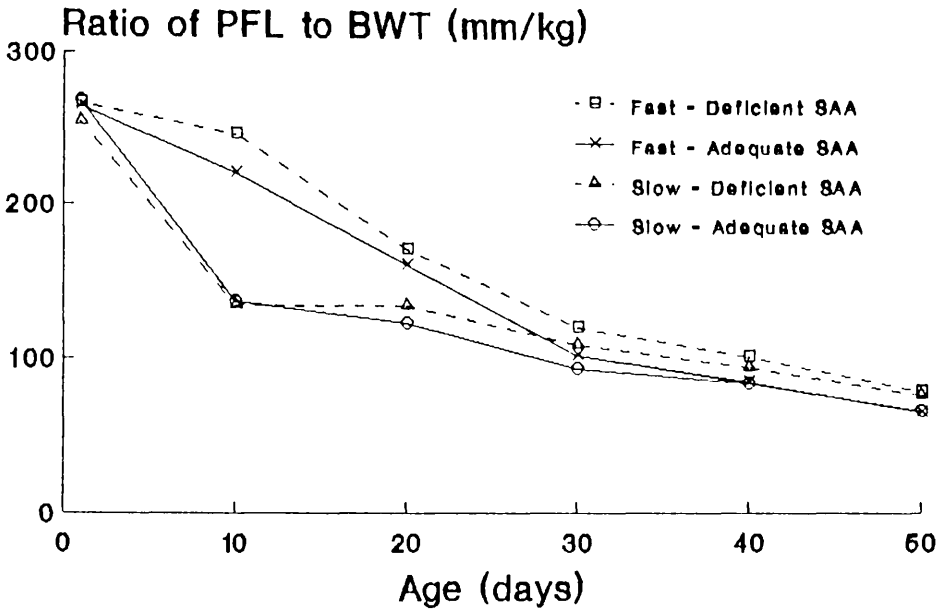
diet 5) for maximum primary, secondary and tail feathers growth (Table 4.14). It is assumed that this requirement difference was due to variations in the rate of feathering.

IV.4.4. The Ratio of Feather Length to Body Weight

The ratio of feather length to body weight was calculated to remove the effect of body weight and thus allow independent differences between line and sex of feather growth to be observed. When the ratio of feather length to body weight (F:B) decreases with age this indicates that feather growth is slower than the body as a whole and that a feather type or tract of feathers is relatively more important early in the life of a chicken. Conversely when the F:B ratio increases with age this indicates that feather growth is relatively faster than the body as a whole and that a feather type or tract is relatively more important later in the development of a chicken. So in the fast line feather growth as expected is relatively faster than the slow line. A higher value for the deficient diet suggests that feather protein is being synthesised at the expense of body protein. The primary, secondary and breast feathers but not the tail feather follows this general rule which suggests that different genes and hormones are involved in tail feather growth.

The F:B ratios of the wing, tail and breast feathers were calculated and the results are shown in Figs. 4.7-4.10 and present the effects of line and diet within sex (Figs.

Male



Female

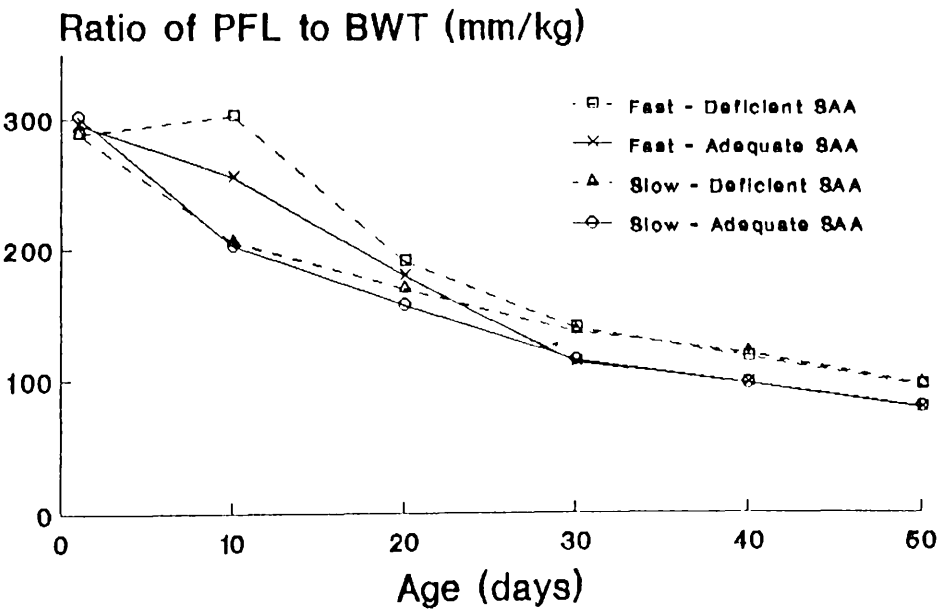
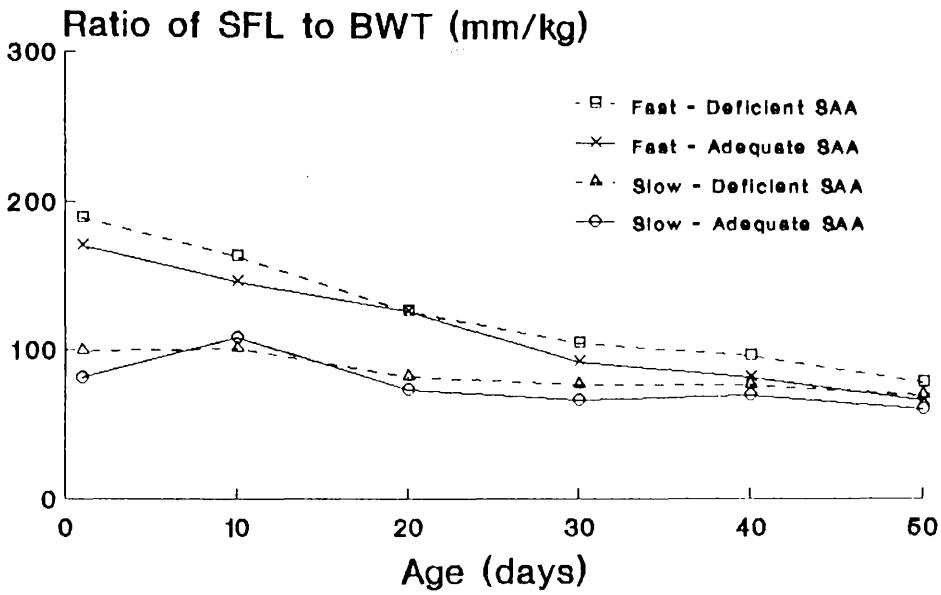


Figure 4.7. Effect of deficient and adequate sulphur amino acid (SAA) diets on the ratio of primary feather length to body weight

Male



Female

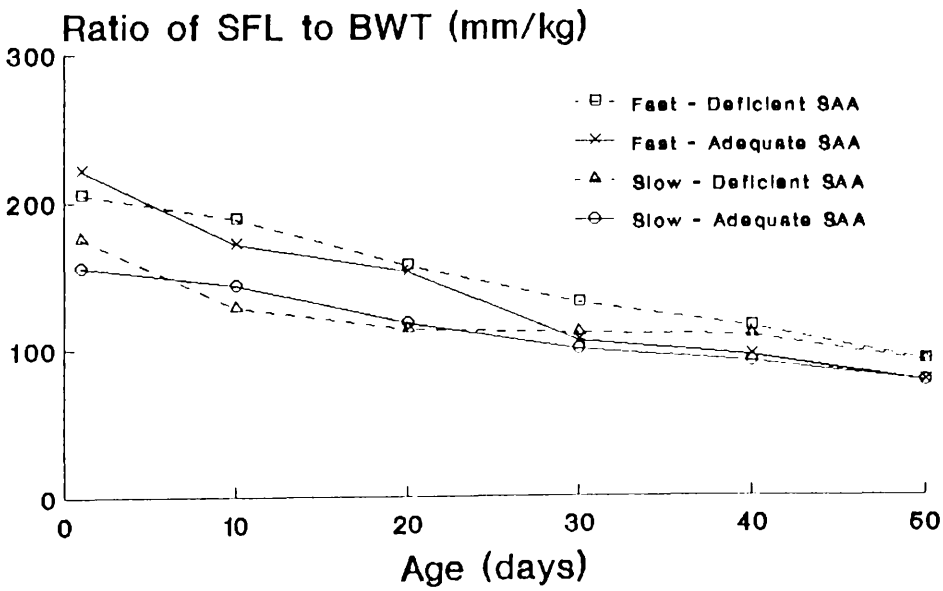


Figure 4.8. Effect of deficient and adequate sulphur amino acid (SAA) diets on the ratio of secondary feather length to body weight

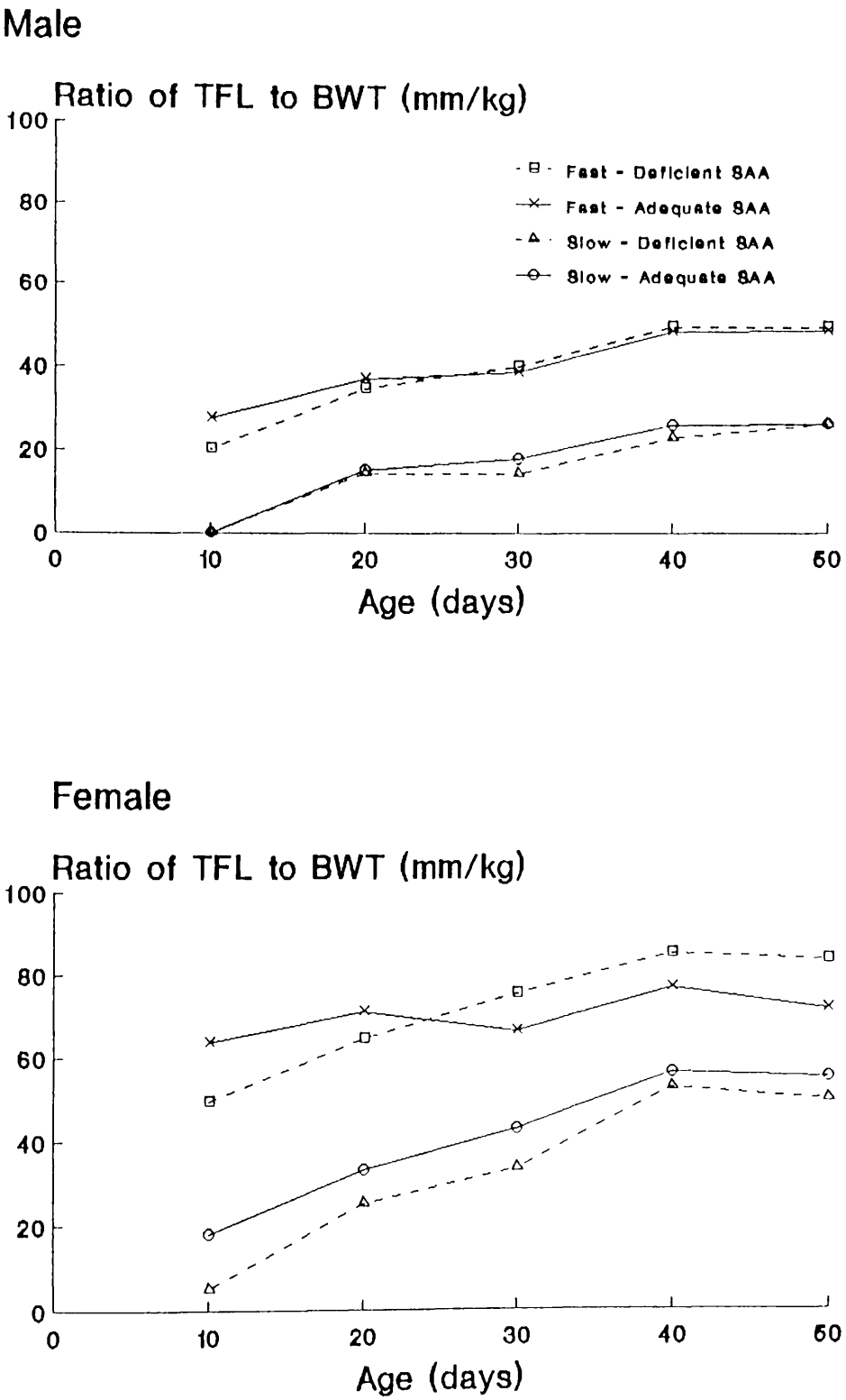
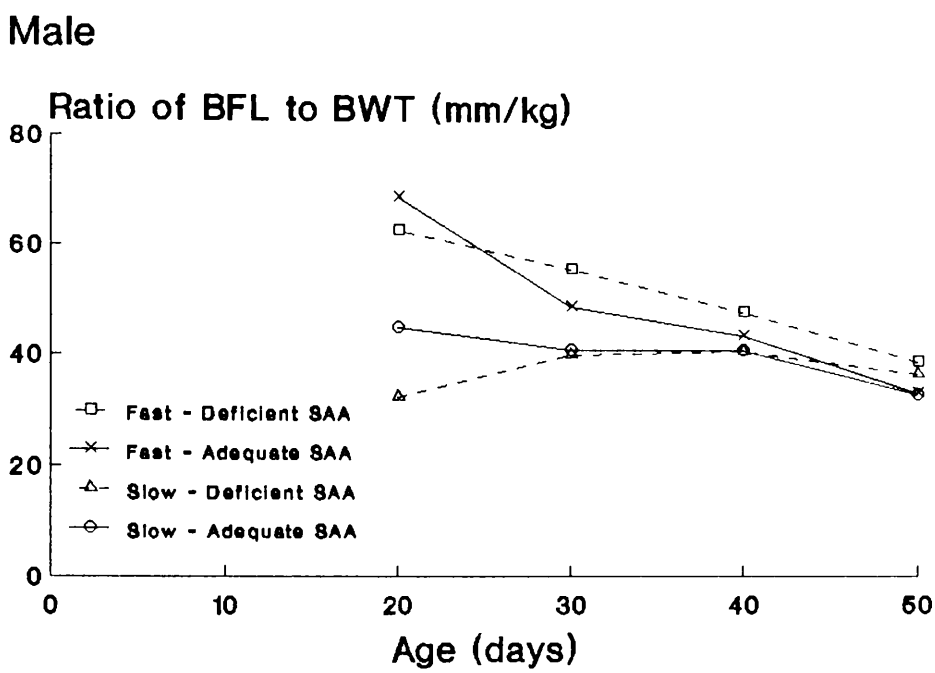


Figure 4.9. Effect of deficient and adequate sulphur amino acid (SAA) diets on the ratio of tail feather length to body weight



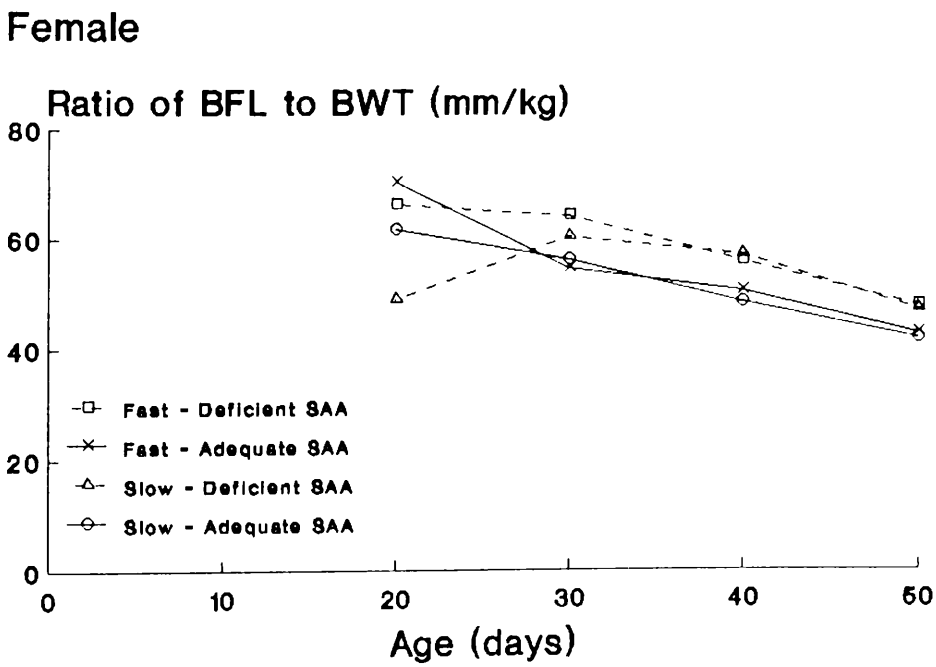


Figure 4.10. Effect of deficient and adequate sulphur amino acid (SAA) diets on the ratio of breast feather length to body weight

4.7 [primary feathers], 4.8 [secondary feathers], 4.9 [tail feathers], 4.10 [breast feathers]). The F:B ratio of primary feathers decreases due to age in both lines, sexes and at the two different levels of SAA (adequate and 80% of SAA requirement). The F:B ratio of secondary feathers also decreased due to age in the fast feathering line, in both sexes and in the two different levels of SAA. But, for slow feathering line the decreasing ratio was not so obvious. The growth of secondary feathers of the males in particular proceeds almost at the same rate as the body. The F:B ratio of tail feathers increases due to age in both lines and both sexes. In this case, the growth of tail feathers accelerates faster than body growth over the first 40 days. While the F:B ratio of breast feathers was more variable due to different sexes, lines and diets throughout 20 to 50 days of their life. Jull (1952) reported that the relationship between feathering and body weight seemed to be at a maximum during the first few weeks after hatching. This is true for all of the feathers examined except for the tail.

The effect of line on growth in the primary, secondary and breast feathers is apparent in females up to about 20 days of age and in males up to 30-40 days of age after which the effect of SAA diet is dominant.

The growth of tail feathers is clearly different to the others studied in this experiment. The effect of selection line dominates the pattern of growth and there is an interaction between line and diet which is more pronounced in the females. In contrast to the effect in the other three

feathers studied, the high SAA diet accelerated feather growth in the slow line and was more dramatic in females. Conversely in the fast line feather growth was relatively faster on the deficient SAA diet (80% of the SAA requirement). Furthermore, the effect of selection for feather growth was most clearly demonstrated in the tail feathers. However, this is not surprising since the selection criterion was 'predicted tail feather length' and this was calculated from a multiple regression equation based on actual tail, primary and secondary feather lengths and back feather score (Edriss, 1988).

One of the most important tracts of feathers in broilers that affects carcass quality is the breast feathers. Divergent selection had an important effect on early growth of these feathers and the effect of dietary SAA during period 0-20 days of age was to make the most dramatic spread of the F:B ratio. The high SAA diet accelerated the already fast growth in the fast line and the low SAA diet decelerated the already slow growth in the slow line. Thus a poor quality starter diet will accentuate the slow rate of feathering seen in the males of some commercial broiler flocks.

It is concluded that the SAA requirements of fast and slow feathering lines for optimum FCR were 9.2 g SAA/kg (0-20 days of age) and 7.3 g SAA/kg (21-50 days of age). The SAA requirements of these birds for maximum growth of the body and feathers are summarised in Table 4.15. Thus while the slow feathering line has slower feather growth the

requirements to achieve maximum body and feather growth are higher than that for the fast feathering line. Generally, the SAA requirement of slow feathering line was found to be higher than the published SAA requirement.

Table 4.15. Digestible sulphur amino acid requirement of the fast and slow feathering lines (g/kg)

Line	Fast				Slow			
Age (days)	0 - 20		21 - 50		0 - 20		21 - 50	
Sex	M	F	M	F	M	F	M	F
Body Weight	7.8	7.3	6.2	5.6	8.5	9.2	7.3	7.3
Feathers Growth	7.8	7.8	6.7	6.7	8.5	9.2	6.7	7.3

The published digestible SAA (methionine + cystine) requirements of the broiler chickens: 0-20 days old= 8.0 g SAA/kg; 21-50 days old= 6.3 g SAA/kg (see Table 4.3).

CHAPTER V. EXPERIMENT 2:

THE RESPONSE OF FEATHER AND BODY GROWTH TO CYSTINE INTAKE

V.1. INTRODUCTION

Most commercial poultry diets are formulated to meet sulphur amino acid (SAA) requirement and quite often are supplemented with methionine. No consideration is given to cystine. Moran (1980) stated that the SAA requirement of growing chickens has been shown to vary extensively. A part of this inconsistency lies in the ability of methionine to substitute as a supplement for cystine, non-equivalency of mass in the conversion, a sparing action by dietary inorganic sulphate, and the usual circumstance where cystine is more limiting than methionine. Having established the responses to total SAA the next logical step in feed formulation for broilers with differing feather growth was to evaluate the responses to cystine, cystine being the dominant amino acid in keratin.

Although a high cystine content may be found in some feedstuffs it may have a low availability, which might be related to poorly digested keratins. Thus for the same reason as in the experiment 1, the digestible amino acids were used in this study. This experiment was conducted to determine the effect of dietary cystine content on feather growth in the fast and slow feathering lines of meat chickens

V.2. MATERIALS AND METHODS

V.2.1. Experimental Design

The experimental design used was a 2 x 2 x 5 factorial with male and female broilers of the fast and slow feathering lines and five cystine levels. Diets contained the same protein and energy levels but five different levels of cystine. The cystine levels ranged from about 80 to 120 per cent of the published requirements. Each treatment was replicated three times with twelve chickens of each sex per replicate.

V.2.2. Birds and Management

To start the experiment 360 male and 360 female broiler chicks of the fast feathering and slow feathering lines were used. These chicks were obtained from eggs of the third generation parents of the fast and slow feathering lines and were housed on 23rd December 1988. The day old chicks were weighed and randomly allocated to the various dietary treatments in such a way that the body weight ranges were equally distributed among all treatments. Initially the chickens were placed in one of the three rooms to ensure that room effects were kept to a minimum as a result of cold weather in the early brooding period. At ten days old, 24 males and 24 females chicks were removed from each pen to other pens (the same dietary treatment) which were located in two other rooms.

V.2.3. Housing

The three rooms functioned as treatment replicates. Each room contained ten floor pens, each with an internal partition to separate males and females. Each pen had dimensions of 280 x 175 cm or each part pen had dimensions of 140 x 175 cm. The layout of the rooms is shown in Fig. 5.1.

The birds were raised in the environmentally controlled rooms. However, during the first week, the brooding heat was provided by one gas brooder within each pen. Temperature on the first day was 34^{o}C and decreased 1^{o}C every two days to get 20^{o}C at 22 days of age. In each room the ventilation was by means of a thermostatically-controlled exhaust fan in the roof, with side wall air inlets.

Within each part pen, two feeding trays and one mini-drinker were provided at the start, then followed by one feeding tube and one bell drinker at five days. After they were separated into three rooms, the drinker space was 8.3 cm/bird and the feeder space was 10.2 cm/bird.

V.2.4. Diets

Birds were fed one of five starter diets (0-15 days of age) and one of five grower diets (16-30 days of age). These starter diets were obtained by mixing a cystine deficient diet with a high cystine diet to get a series of five starter diets. The methionine level was chosen with reference to experiment 1. Grower diets were obtained by

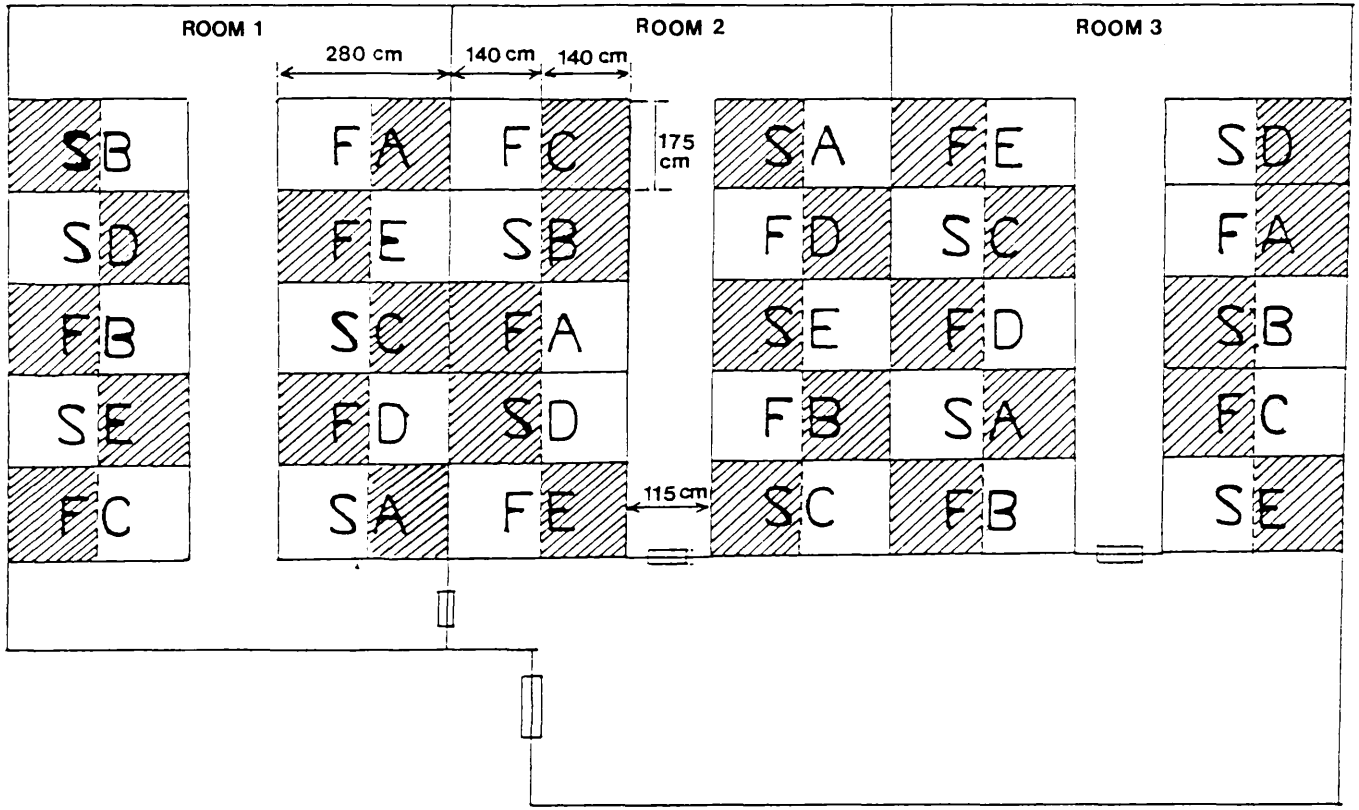


Figure 5.1. The layout of the rooms (experiment 2).
F= Fast, S= Slow; A,B,C,D,E= Diet Series; n= 12 birds/pen;
☐ = Male, ▨ = Female

mixing the starter diets (DCP= 230 g/kg; ME= 12.7 MJ/kg) with the dilution mixture diet (DCP= 0 g/kg; ME= 12.7 MJ/kg) to get the series of five grower diets (DCP= 200 g/kg; ME= 12.7 MJ/kg). The dilution mixture was formulated to contain the same ME as the starter but with a low calcium and phosphorus content so the level of these minerals in the grower feed would be appropriate for that stage. The proportions mixed of the cystine deficient diet (diet 1) and the high cystine diet (diet 5) were 100:0, 75:25; 50:50, 25:75 and 0:100 for the five diets. The levels of cystine in the series of five diets ranged from about 80 to 120 per cent of published requirements. The diets were produced so that the cystine would the first limiting amino acid and thus responses would be due to cystine intake.

The composition and the analysis of feeds used are shown in Tables 5.1, 5.2 and 5.3. The digestible amino acid requirements of meat chickens and the digestible amino acid content of the five series diets can be seen in Tables 5.4 and 5.5.

V.2.5. Recording Procedure

a. Body Weight and Feather Length

On receipt the chicks were wing banded, and weighed individually using a Mettler PM6000 balance. Subsequently, every five days the chickens were weighed individually from 5 to 30 days of age.

Table 5.1. Composition of experimental basal diets (kg)

Ingredients	Diet A	Diet E	Dilution mixture
Wheat (10.6)*	74.5	141.1	-
Maize (9.2)	207.3	146.0	-
Maize gluten meal (56.0)	27.0	95.0	-
Soyabean meal (41.0)	338.5	300.0	-
Fish meal, White (61.7)	38.4	60.0	-
Meat&Bone meal (50/1)	50.0	38.7	-
FF soya (35.6)	-	27.8	-
Maize starch	200.0	170.0	744.8
Maize oil	9.4	7.3	17.2
Oathulls (5.8)	-	-	220.0
Dicalcium Phosphate	-	-	8.2
Limestone	6.8	6.14	0.3
Salt	1.6	1.3	3.9
DL-Methionine	0.1	0.06	-
L-Cystine	-	1.0	-
Casein (85.0)	40.8	-	-
Vitamin & mineral mix **	5.0	5.0	5.0
Coccidiostat (Avatec Premix)	0.6	0.6	0.6
Total	1,000.0	1,000.0	1,000.0

* Values in parentheses are the percentage crude protein in the ingredients, and the protein and fat content of meat and bone meal (50/1)

** Vitamin and mineral mix provides per kilogram of diet: vitamin A, 14,480 IU; vitamin D3, 5,400 IU; vitamin E, 35 IU; Biotin, 150 ug; copper, 15 mg, selenium, 0.2 mg; molybdenum, 1.5 mg.

Starter Diets:

Diet A = 100% Diet A + 0% Diet E
Diet B = 75% Diet A + 25% Diet E
Diet C = 50% Diet A + 50% Diet E
Diet D = 25% Diet A + 75% Diet E
Diet E = 0% Diet A + 100% Diet E

Grower Diets:

Diet A = 88.5% Starter Diet A + 11.5% Dilution Diet
Diet B = 88.5% Starter Diet B + 11.5% Dilution Diet
Diet C = 88.5% Starter Diet C + 11.5% Dilution Diet
Diet D = 88.5% Starter Diet D + 11.5% Dilution Diet
Diet E = 88.5% Starter Diet E + 11.5% Dilution Diet

Table 5.2. Calculated analysis of experimental diets

	Starter Diets		Dilution Diet	Grower Diets	
	A	E		A	E
- ME (MJ/kg)	12.7	12.7	12.7	12.7	12.7
- Crude Protein (g/kg)	265.0	270.0	13.0	236.0	240.0
- Dig.Protein (g/kg)	230.0	230.0	10.1	204.0	204.0
- Dig.Methionine (g/kg)	4.6	4.6	0.1	4.0	4.0
- Dig. Cystine (g/kg)	2.8	4.4	0.1	2.5	3.9
- Dig. Meth+Cyst (g/kg)	7.3	8.9	0.2	6.5	7.9
- Calcium (g/kg)	13.6	13.2	1.4	12.2	12.0
- Av.Phosphorus (g/kg)	7.9	7.8	0.7	7.1	7.0
- Ether Extract (g/kg)	24.4	27.4	20.3	23.9	26.6
- Crude Fibre (g/kg)	18.7	19.9	63.1	23.8	24.9

Table 5.3. Calculated and chemical analysis of experimental diets

	Starter Diets					Grower Diets				
	A	B	C	D	E	A	B	C	D	E
Calculated Analysis:										
- Digest. Protein (g/kg)	230.0	230.0	230.0	230.0	230.0	200.0	200.0	200.0	200.0	200.0
- Digest.Methionine (g/kg)	4.6	4.6	4.6	4.6	4.6	4.0	4.0	4.0	4.0	4.0
- Digest. Cystine (g/kg)	2.7	3.1	3.5	3.9	4.3	2.4	2.7	3.0	3.4	3.8
- Digest. Meth+Cyst (g/kg	7.3	7.7	8.1	8.5	8.9	6.4	6.7	7.0	7.4	7.8
Chemical Analysis:										
- Crude Protein (g/kg)	267.0	270.0	269.0	268.0	269.0	231.0	233.0	230.0	230.0	233.0
- Calcium (g/kg)	12.4	12.7	11.9	11.6	11.7	11.5	11.7	11.3	11.0	11.2
- Phosphorus (g/kg)	7.6	8.2	7.7	7.6	7.6	7.2	7.3	7.1	7.0	7.1
- Ether Extract (g/kg)	24.7	25.4	26.9	29.3	32.6	25.2	25.8	26.6	29.5	28.5

Table 5.4. Digestible amino acids requirements of the broiler chickens (g/kg)*

Essential Amino Acids	Period I (0-15 Days of Age)	Period II (16-30 Days of Age)
Arginine	11.4 (5.0)**	8.8 (4.4)
Histidine	4.3 (1.9)	3.4 (1.7)
Isoleucine	6.9 (3.0)	6.0 (3.0)
Leucine	13.6 (5.9)	10.2 (5.1)
Lysine	10.3 (4.5)	8.6 (4.3)
Methionine	4.6 (2.0)	3.8 (1.9)
Cystine	3.4 (1.5)	3.0 (1.5)
Meth + Cystine	8.0 (3.5)	6.6 (3.3)
Tyros + Phenyl	13.8 (6.0)	11.6 (5.8)
Threonine	5.8 (2.5)	5.0 (2.5)
Tryptophan	2.0 (0.9)	1.4 (0.7)
Valine	8.4 (3.7)	6.0 (3.0)

* Adapted from Table 4.3.

** Values in the brackets are digestible amino acids requirements as a percentage of protein

Table 5.5. Digestible amino acid contents (g/kg) of the diets for period I (0-15 days of age) and period II (16-30 days of age)

Essential Amino Acids	Diets (Period I) A	Diets (Period I) E	Diets (Period II) A	Diets (Period II) E
Arginine	14.3 (1.25)*	14.3 (1.25)	12.5 (1.42)	12.2 (1.39)
Histidine	5.6 (1.30)	5.5 (1.28)	4.9 (1.44)	4.8 (1.41)
Isoleucine	10.7 (1.55)	10.3 (1.49)	9.3 (1.55)	9.0 (1.50)
Leucine	19.7 (1.45)	21.4 (1.57)	17.0 (1.67)	18.5 (1.81)
Lysine	13.9 (1.35)	12.0 (1.17)	12.0 (1.40)	10.4 (1.21)
Methionine	4.6 (1.00)	4.6 (1.00)	4.0 (1.05)	4.0 (1.05)
Cystine	2.7 (0.79)	4.3 (1.26)	2.4 (0.80)	3.8 (1.27)
Meth + Cystine	7.3 (0.91)	8.9 (1.11)	6.4 (0.97)	7.8 (1.18)
Tyros + Phenyl	20.0 (1.45)	19.5 (1.41)	17.4 (1.50)	17.0 (1.47)
Threonine	9.0 (1.55)	8.6 (1.48)	7.8 (1.56)	7.5 (1.50)
Tryptophan	2.5 (1.25)	2.4 (1.20)	2.3 (1.64)	2.1 (1.50)
Valine	11.8 (1.40)	11.4 (1.36)	10.2 (1.70)	9.9 (1.65)

* Values in the brackets are digestible amino acid contents expressed as multiples of the requirements of starting or growing broilers.

Primary and secondary wing feather lengths were recorded at one day of age (i.e. the day after wing banding). Every five days subsequently from 5 to 30 days of age the measurement of primary, secondary, tail, back and breast feather lengths were carried out. The methods of feather measurements can be seen in Chapter III. From a visual assessment of birds in experiment 1, it seems that the fast and slow feathering lines had a difference in thigh feather length. To determine if the thigh feathers are affected by dietary cystine content, in this study the thigh feather length of the right part of the body was measured from the base of the pin feather to the farthest point of emergence.

b. Feed Intake

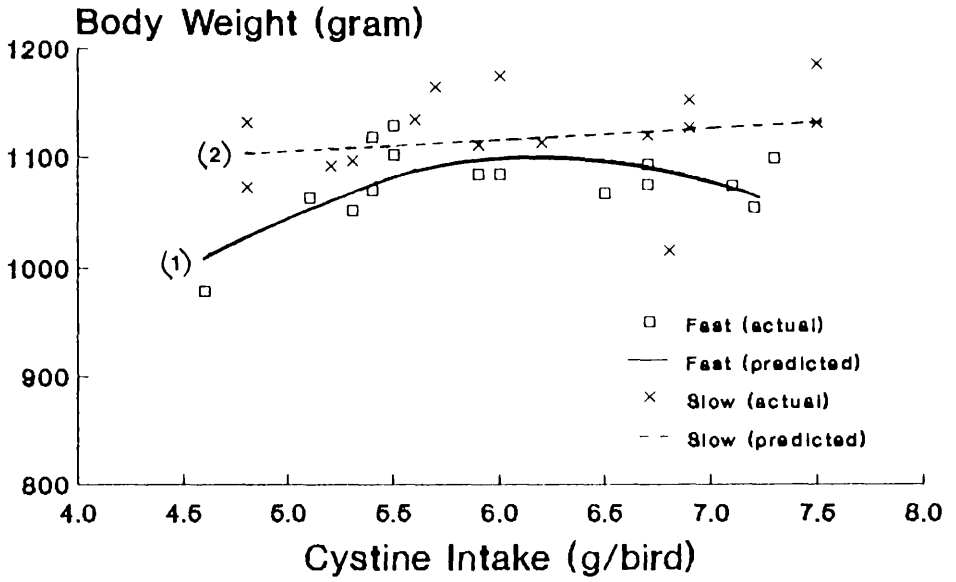
Three kilograms lots of each diet were weighed and put into plastic bags. Thus, the feed had been prepared before the feed in the tube feeder was empty. Every five days, the feed remaining in the tube feeder was weighed. Therefore, the difference between the feed given and feed remaining was assumed to be feed intake. The feed intakes per bird/day were calculated every five days, on a pen basis taking into account the number of chickens alive at the beginning and end of each period.

V.3. RESULTS

The experiment was conducted over 30 days period since the first experiment showed that the fast and slow feathering lines had large differences in feather growth during the first 30 days of their life and these might be expected to show up a differential in cystine requirements. The results of this experiment from 0 to 30 days of age can be seen in Appendices 6-11. Generally, to determine a relationship between body weight and cystine intake or feather lengths and cystine intake at 30 days of age, quadratic regression equations were calculated. It was found that the coefficient of determination (R^2) in many equations was low and for some it was zero. Overall the R^2 varied from 0-67 per cent. It means that the percentage variation in the length of some feathers was only mildly less influenced by variations in cystine intake. However, there is a maximum response in body weight due to cystine intake, except in the slow feathering males (Fig. 5.2). Only the slow feathering females show a maximum response in the lengths of primary and secondary feathers due to cystine intake (Figs. 5.3, 5.4 and 5.5). It seems that the slow feathering females were more responsive to cystine intake than the slow feathering males and both sexes in the fast feathering line.

To show if there was a difference in the performance of the birds during two growth phases, the results of cumulative feed intake, cumulative cystine intake and feed conversion ratio (FCR) are presented in two periods, period I (0-15 days of age) and period II (16-30 days of age). Body

Male



Female

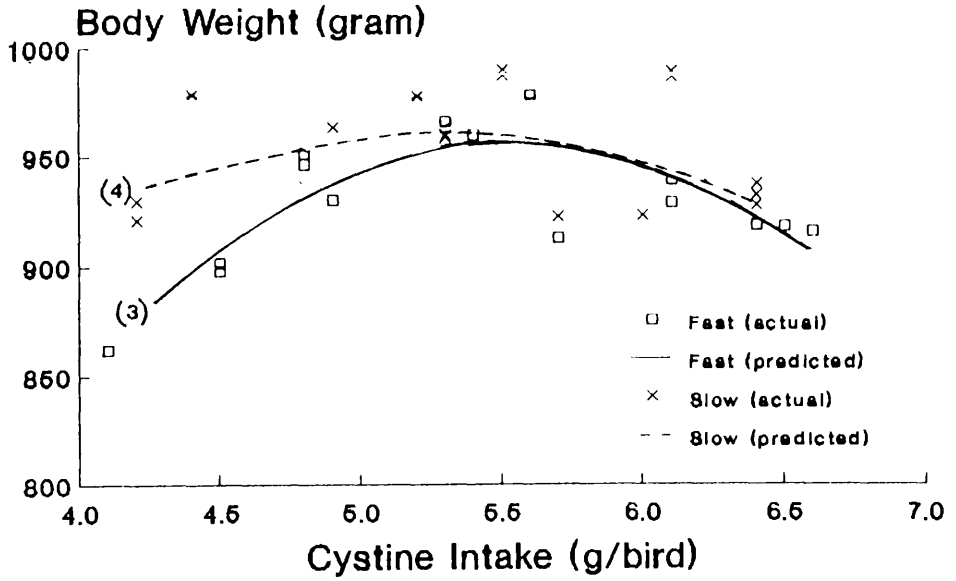


Figure 5.2. The predicted and actual body weight response to cystine intake at 30 days of age.
(1) $Y=-363+471X-37.8X^2$ ($R^2=37.2\%$); (2) $Y=1105-7X+1.5X^2$ ($R^2=0\%$);
(3) $Y=-389+487X-44.0X^2$ ($R^2=66.6\%$); (4) $Y=305+249X-23.6X^2$ ($R^2=46.3\%$)

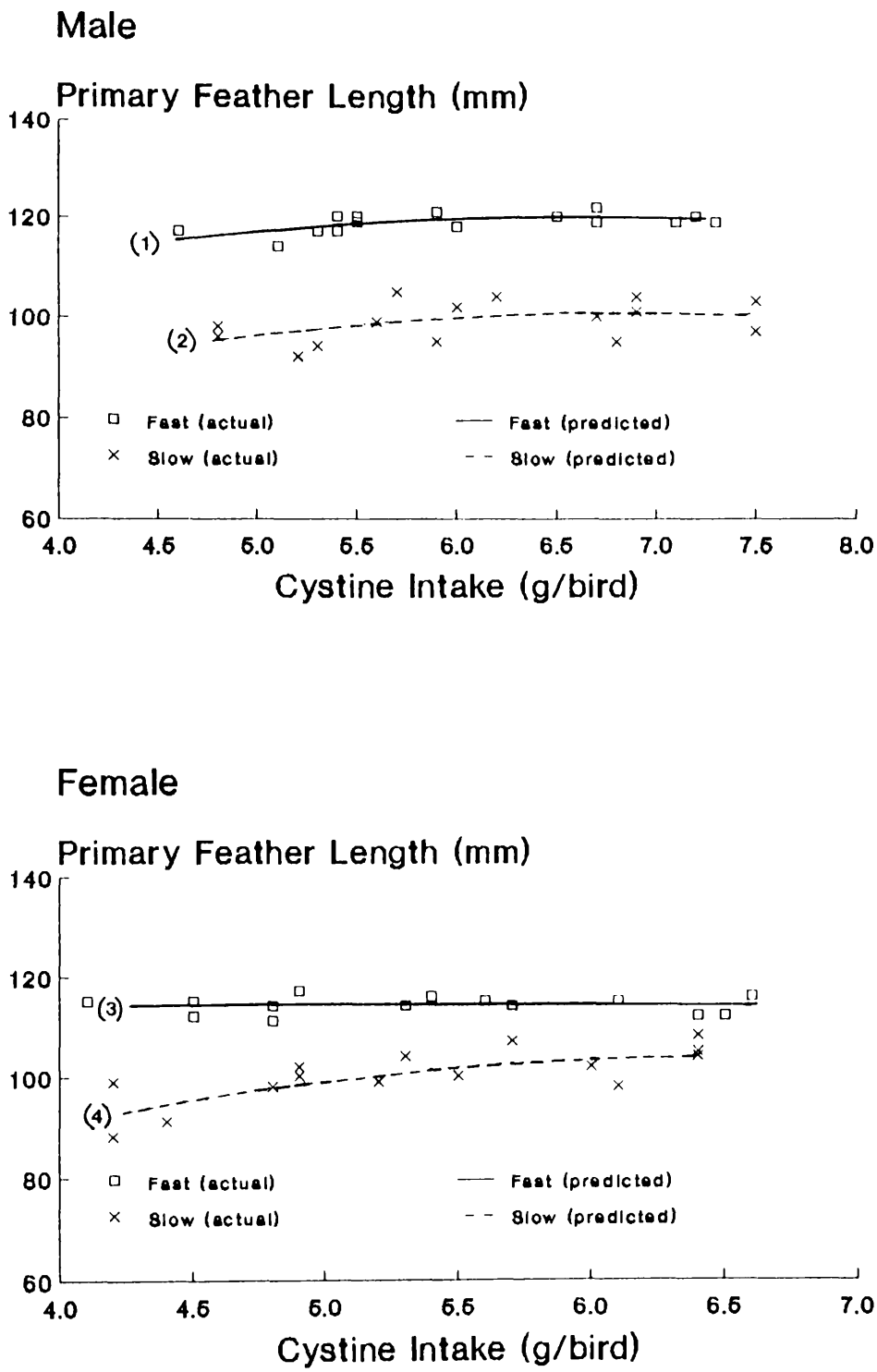


Figure 5.3. The predicted and actual primary feather length response to cystine intake at 30 days of age.
(1) $Y=68.9+15.5X-1.17X^2$ ($R^2=30.4\%$); (2) $Y=38.2+18.3X-1.33X^2$ ($R^2=8.2\%$)
(3) $Y=101+5.21X-0.487X^2$ ($R^2=0\%$); (4) $Y=4.8+31.2X-2.45X^2$ ($R^2=51.1\%$)

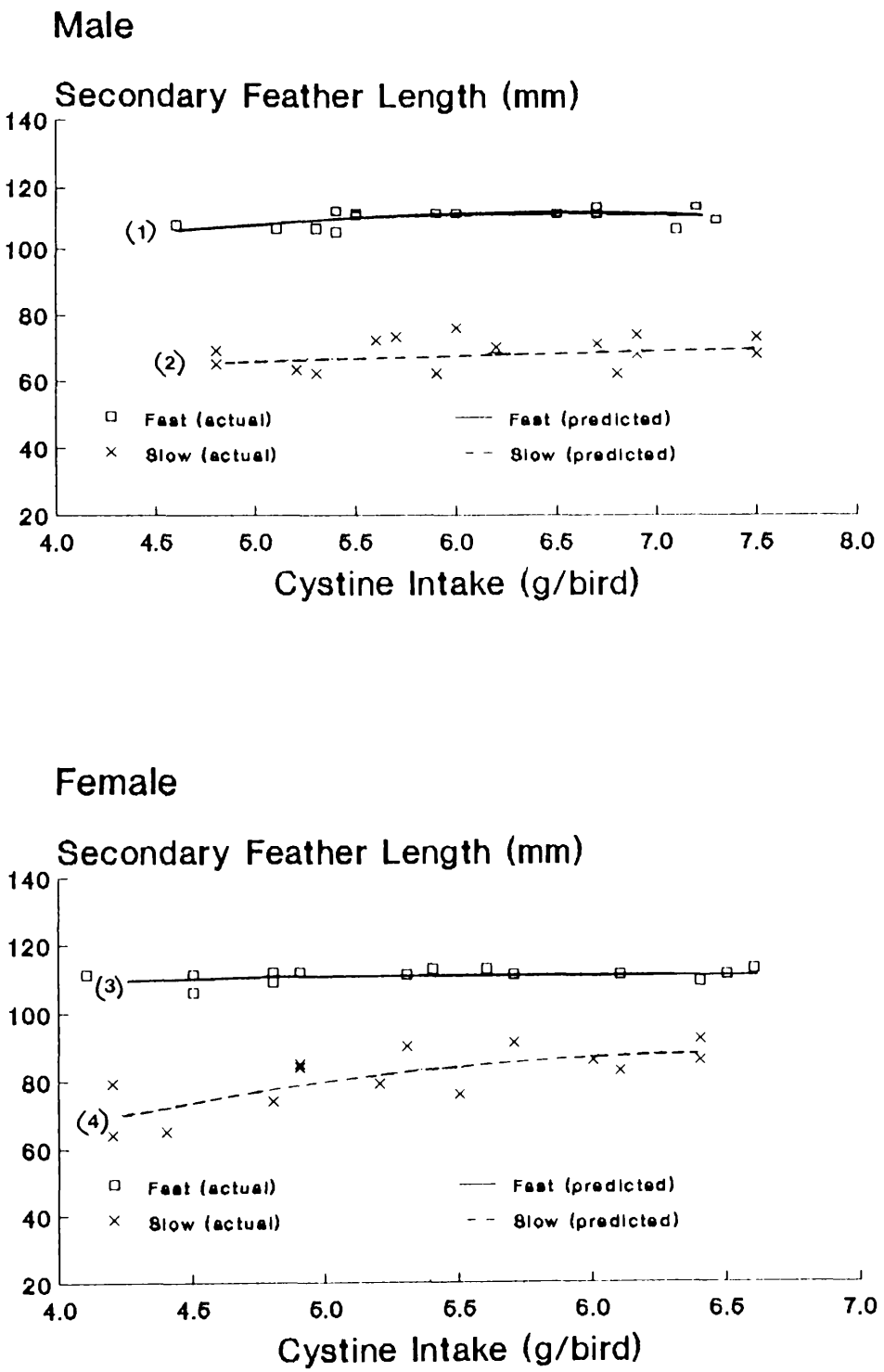


Figure 5.4. The predicted and actual secondary feather length response to cystine intake at 30 days of age.
(1) $Y=42.5+21.0-1.60X^2$ (R^2=16.9%); (2) $Y=31.8+10.5X-0.73X^2$ (R^2=0%)
(3) $Y=86.0+8.78X-0.755X^2$ (R^2=0%); (4) $Y=-60.7+45.6X-3.48X^2$ (R^2=51.1%)

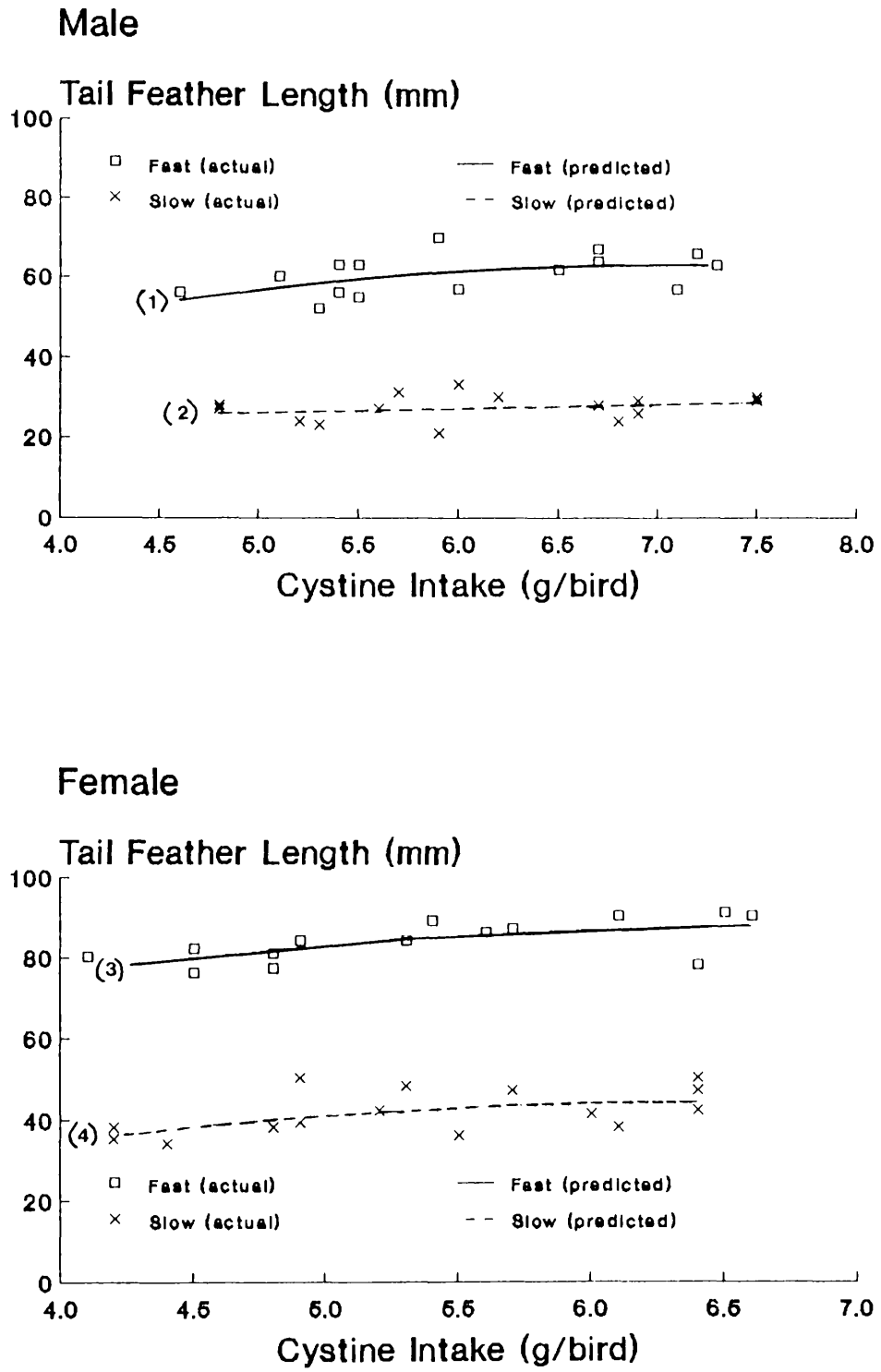


Figure 5.5. The predicted and actual tail feather length response to cystine intake at 30 days of age.
(1) $Y=-18.4+23.5X-1.69X^2$ ($R^2=15.2\%$); (2) $Y=31.5-2.4X+0.27X^2$ ($R^2=0\%$);
(3) $Y=17.4+20.9X-1.55X^2$ ($R^2=36.2\%$); (4) $Y=-25.1+21.8X-1.71X^2$ ($R^2=15.6\%$).

weight and feathering are shown at 15 and 30 days of age.

V.3.1. Feed Intake, Cystine Intake and Feed Conversion Ratio

There was no significant effect of line on cumulative feed intake and cystine intake. However, feed conversion ratio (FCR) was significantly affected by line, sex and diet, during period I and II (Tables 5.6 and 5.7). During the first period, generally, the fast feathering line had better FCR than the slow feathering line. Males had better FCR than females in both periods.

During period I, the birds fed diet C had better FCR than those fed the other diets. But, slow feathering females fed diet D had a much better FCR than those fed diet C. In the second period, the females of the fast and slow feathering lines fed diet C and the males of the both lines fed diet E had better FCR than those fed the other diets.

V.3.2. Body Weight and Feather Lengths

The effects of line and sex were significant on live body weight and all feather length measurements at 15 and 30 days of age. At 15 days of age, only body weight and tail feather length were significantly influenced by diet (Table 5.8). However, at 30 days of age, body weight and almost all feather length measurements had been affected by diets, except for breast feather length (Table 5.9).

Table 5.6. Effects of line, sex and diet on feed intake, sulphur amino acid intake, cystine intake, feed conversion ratio and body weight gain during period I (0–15 days of age)

Line/ Sex	Diet	Cumulative Feed Intake (g/b/d)	Cumulative SAA Intake (mg/b/d)	Cumulative Cystine Intake (mg/b/d)	FCR [1)]	Body Weight Gain (g/b/d)
FF	A	30.7	224.2	86.0	1.61	19.0
	B	29.3	225.6	93.8	1.50	19.5
	C	30.5	247.3	110.0	1.47	20.8
	D	30.3	257.8	121.5	1.55	19.6
	E	29.0	257.8	127.5	1.50	19.3
FM	A	31.4	229.8	88.2	1.51	20.9
	B	31.1	239.3	99.3	1.46	21.3
	C	30.4	246.2	109.3	1.42	21.4
	D	31.2	265.3	124.7	1.45	21.5
	E	30.3	269.6	133.1	1.45	20.8
SF	A	30.2	220.9	84.6	1.61	18.8
	B	29.8	251.8	95.6	1.57	19.0
	C	29.3	236.9	105.3	1.51	19.4
	D	27.4	233.3	109.5	1.46	18.8
	E	28.9	257.3	127.3	1.57	18.4
SM	A	32.2	234.9	90.0	1.59	20.3
	B	31.6	243.8	101.3	1.57	20.2
	C	31.2	252.4	112.2	1.48	21.0
	D	32.5	276.0	130.0	1.55	20.9
	E	31.7	282.0	139.3	1.52	20.8
SED		1.05	11.09	3.92	0.04	0.57

FF = Fast Female; FM = Fast Male; SF = Slow Female; SM = Slow Male

1) FCR = Feed Conversion Ratio = g feed/g body weight gain

(.....continued)

Table 5.6. (continued)

	Cumulative Feed Intake (g/b/d)	Cumulative SAA Intake (mg/b/d)	Cumulative Cystine Intake (mg/b/d)	FCR [1]	Body Weight Gain (g/b/d)
MAIN EFFECTS					
Line - Fast	30.4	246.3	109.3	1.49	20.4
- Slow	30.5	248.9	109.5	1.54	19.8
SED	0.33	3.51	1.24	0.01	0.18
Sex - Male	31.4	253.9	112.8	1.50	20.9
Female	29.6	241.3	106.1	1.54	19.3
Diet - A	31.1	227.4	87.2	1.58	19.7
- B	30.5	240.1	97.5	1.52	20.0
- C	30.3	245.7	109.2	1.47	20.7
- D	30.4	258.1	121.4	1.50	20.2
- E	30.0	266.7	131.8	1.51	19.8
SED	0.53	5.54	1.96	0.02	0.28
Significance of Differences:					
Line (L)	NS	NS	NS	***	***
Sex (S)	***	***	***	**	***
Diet (D)	NS	***	***	***	**
L x S	*	NS	**	**	NS
L x D	NS	NS	NS	NS	NS
S x D	NS	NS	NS	NS	NS
L x S x D	NS	NS	NS	NS	NS

NS = Non Significant; * = P < 0.05 ; ** = P < 0.01 ; *** = P < 0.001

1) FCR = Feed Conversion Ratio = g feed/g body weight gain

Table 5.7. Effects of line, sex and diet on feed intake, sulphur amino acid intake, cystine intake, feed conversion ratio and body weight gain during period II (16-30 days of age)

Line/ Sex	Diet	Cumulative Feed Intake (g/b/d)	Cumulative SAA Intake (mg/b/d)	Cumulative Cystine Intake (mg/b/d)	FCR [1)]	Body Weight Gain (g/b/d)
FF	A	84.9	543.1	203.8	2.30	36.9
	B	84.2	564.0	227.3	2.11	40.0
	C	83.8	586.4	251.6	2.06	40.7
	D	80.8	597.5	274.4	2.07	39.0
	E	80.8	630.2	307.1	2.08	38.8
FM	A	104.1	666.2	250.0	2.27	45.7
	B	96.0	643.3	259.3	1.97	48.7
	C	92.1	644.8	276.4	1.95	47.3
	D	93.9	694.4	319.3	1.99	47.2
	E	91.0	709.7	345.8	1.91	47.7
SF	A	83.3	533.3	200.0	2.04	41.0
	B	84.6	544.8	228.5	2.03	41.6
	C	82.8	579.5	248.4	1.95	42.5
	D	83.4	617.1	283.6	2.02	41.3
	E	79.3	618.7	301.3	1.95	40.7
SM	A	100.1	640.4	240.4	2.00	50.1
	B	99.0	663.1	267.1	1.90	52.1
	C	97.1	679.7	291.3	1.89	51.3
	D	95.9	709.3	326.0	1.86	51.6
	E	90.2	703.3	342.9	1.80	50.2
SED		3.17	22.59	8.95	0.06	1.54

FF = Fast Female; FM = Fast Male; SF = Slow Female; SM = Slow Male

1) FCR = Feed Conversion Ratio = g feed/g body weight gain

(.....continued)

Table 5.7. (continued)

	Cumulative Feed Intake (g/b/d)	Cumulative SAA Intake (mg/b/d)	Cumulative Cystine Intake (mg/b/d)	FCR [1)]	Body Weight Gain (g/b/d)
MAIN EFFECTS					
Line - Fast	89.2	628.0	271.5	2.07	43.2
Slow	89.6	628.9	273.0	1.94	46.2
SED	1.00	7.14	2.83	0.02	0.49
Sex - Male	95.9	675.4	291.9	1.96	49.2
Female	82.8	581.5	252.6	2.06	40.3
SED	1.00	7.14	2.83	0.02	0.49
Diet - A	93.1	595.8	223.6	2.15	43.4
- B	90.9	603.8	245.6	2.00	45.6
- C	89.0	622.6	266.9	1.96	45.4
- D	88.5	654.6	300.8	1.99	44.8
- E	85.3	665.5	324.3	1.94	44.4
SED	1.59	11.29	4.47	0.03	0.77
Significance of Differences:					
Line (L)	NS	NS	NS	***	***
Sex (S)	***	***	***	***	***
Diet (D)	NS	***	***	***	*
L x S	*	NS	NS	NS	NS
L x D	NS	NS	NS	**	NS
S x D	NS	NS	NS	NS	NS
L x S x D	NS	NS	NS	NS	NS

NS = Non Significant; * = P < 0.05 ; ** = P < 0.01 ; *** = P < 0.001

1) FCR = Feed Conversion Ratio = g feed/g body weight gain

Table 5.8. Effects of line, sex and diet on live body weight and feather lengths at 15 Days of Age

Line/ Sex	Diet	Live Body Weight (gram)	Primary Feather Length (mm)	Secondary Feather Length (mm)	Tail Feather Length (mm)	Back Feather Length (mm)	Breast Feather Length (mm)	Thigh Feather Length (mm)
FF	A	332.7	73.3	56.3	28.7	10.7	16.0	23.0
	B	342.8	74.7	58.7	28.7	11.0	15.7	23.0
	C	358.6	77.7	61.3	30.7	11.0	16.0	24.3
	D	342.1	77.7	61.3	32.3	12.0	17.0	24.3
	E	335.1	75.7	60.3	31.7	11.3	15.3	23.7
FM	A	362.6	69.3	51.3	17.7	7.7	12.3	19.3
	B	370.0	72.0	51.7	18.0	8.0	12.0	19.7
	C	371.1	71.7	51.7	19.0	8.7	13.0	20.3
	D	372.6	73.7	53.3	21.7	8.7	13.3	21.3
	E	362.1	73.3	53.7	19.3	9.0	13.0	22.0
SF	A	328.9	45.7	27.7	10.7	3.7	7.0	9.3
	B	329.8	46.7	30.3	10.7	4.3	7.0	9.0
	C	338.4	47.0	30.0	11.0	4.3	6.7	9.3
	D	325.6	46.7	32.3	11.0	4.3	7.0	9.7
	E	322.3	50.7	32.7	12.0	4.7	7.0	11.0
SM	A	347.9	39.0	25.0	7.3	0.3	4.7	7.0
	B	350.7	40.3	25.0	7.0	1.0	3.7	6.7
	C	364.2	40.0	24.7	7.3	1.0	4.0	7.0
	D	360.7	41.3	27.0	7.0	1.7	3.7	6.0
	E	358.7	37.3	22.3	7.7	1.7	4.0	6.0
SED		8.49	2.25	2.19	1.43	0.80	0.87	1.27

FF= Fast Female; FM= Fast Male; SF= Slow Female; SM= Slow Male

(.....continued)

Table 5.8. (continued)

	Live Body Weight (gram)	Primary Feather Length (mm)	Secondary Feather Length (mm)	Tail Feather Length (mm)	Back Feather Length (mm)	Breast Feather Length (mm)	Thigh Feather Length (mm)
MAIN EFFECTS							
Line - Fast	355.0	73.9	56.0	24.8	9.8	14.4	22.1
Slow	342.7	43.5	27.7	9.2	2.7	5.5	8.1
SED	2.68	0.71	0.69	0.45	0.25	0.28	0.40
Sex - Male	362.1	55.8	38.6	13.2	4.8	8.4	13.5
Female	335.6	61.6	45.1	20.7	7.7	11.5	16.7
SED	2.68	0.71	0.69	0.45	0.25	0.28	0.40
Diet - A	343.0	56.8	40.1	16.1	5.6	10.0	14.7
B	348.3	58.4	41.4	16.1	6.1	9.6	14.6
C	358.1	59.1	41.9	17.0	6.3	9.9	15.3
D	350.2	59.8	43.5	18.0	6.7	10.3	15.3
E	344.5	59.3	42.3	17.7	6.7	9.8	15.7
SED	4.24	1.13	1.09	0.72	0.40	0.44	0.64
Significance of Differences:							
Line (L)	***	***	***	***	***	***	***
Sex (S)	***	***	***	***	***	***	***
Diet (D)	**	NS	NS	*	NS	NS	NS
L x S	NS	**	NS	***	NS	NS	NS
L x D	NS	NS	NS	NS	NS	NS	NS
S x D	NS	NS	NS	NS	NS	NS	NS
L x S x D	NS	NS	NS	NS	NS	NS	NS

NS = Non Significant; * = P < 0.05 ; ** = P < 0.01 ; *** = P < 0.001

Table 5.9. Effects of line, sex and diet on live body weight and feather lengths at 30 days of age

Line/ Sex	Diet	Live Body Weight (gram)	Primary Feather Length (mm)	Secondary Feather Length (mm)	Tail Feather Length (mm)	Back Feather Length (mm)	Breast Feather Length (mm)	Thigh Feather Length (mm)
FF	A	886.8	114.0	109.3	79.3	38.0	45.0	57.3
	B	942.5	114.0	111.0	80.7	38.3	47.3	57.0
	C	968.8	115.0	112.3	86.3	39.7	47.3	59.3
	D	926.8	114.7	111.0	89.0	39.7	47.0	60.7
	E	917.5	113.3	111.0	86.3	38.7	46.7	58.3
FM	A	1048.7	117.0	108.0	57.0	36.0	44.3	54.3
	B	1100.1	118.7	109.3	57.0	36.0	45.0	53.7
	C	1080.4	118.7	109.0	63.3	35.7	44.7	54.0
	D	1079.8	120.3	112.0	64.3	36.7	46.7	57.3
	E	1077.3	119.3	109.7	62.0	37.3	45.0	57.0
SF	A	943.4	92.7	69.3	35.7	22.7	34.3	33.7
	B	954.4	100.0	81.0	42.3	27.0	37.0	38.7
	C	975.9	101.0	81.7	42.0	28.0	36.7	38.7
	D	945.0	102.3	86.7	42.0	28.7	38.7	41.3
	E	932.6	105.7	90.0	46.3	31.0	41.3	45.3
SM	A	1099.0	95.3	65.7	26.3	18.7	32.0	32.3
	B	1132.4	99.3	69.0	27.0	19.3	32.3	33.3
	C	1133.9	100.3	69.3	28.0	19.0	32.0	33.7
	D	1134.3	101.7	71.0	27.7	21.0	32.3	33.0
	E	1112.0	98.3	67.7	27.7	20.7	33.7	34.0
SED		26.84	2.51	3.60	3.58	1.97	1.90	2.54

FF= Fast Female; FM= Fast Male; SF= Slow Female; SM= Slow Male

(.....continued)

Table 5.9. (continued)

Line/ Sex	Diet	Live Body Weight (gram)	Primary Feather Length (mm)	Secondary Feather Length (mm)	Tail Feather Length (mm)	Back Feather Length (mm)	Breast Feather Length (mm)	Thigh Feather Length (mm)
MAIN EFFECTS								
Line -	Fast	1002.9	116.5	110.3	72.5	37.6	45.9	56.9
	Slow	1036.3	99.7	75.1	34.5	23.6	35.0	36.4
SED		8.49	0.79	1.14	1.13	0.62	0.60	0.80
Sex -	Male	1099.8	108.9	89.1	44.0	28.0	38.8	44.3
	Female	939.4	107.3	96.3	63.0	33.2	42.1	49.0
SED		8.49	0.79	1.14	1.13	0.62	0.60	0.80
Diet -	A	994.5	104.8	88.1	49.6	28.8	38.9	44.4
	B	1032.4	108.0	92.6	51.8	30.2	40.4	45.7
	C	1039.8	108.8	93.1	54.9	30.6	40.2	46.4
	D	1021.5	109.8	95.2	55.8	31.5	41.2	48.1
	E	1009.8	109.2	94.6	55.6	31.9	41.7	48.7
SED		13.42	1.25	1.80	1.79	0.98	0.95	1.27
Significance of Differences:								
Line (L)		***	***	***	***	***	***	***
Sex (S)		***	*	***	***	***	***	***
Diet (D)		*	**	**	**	*	NS	*
L x S		NS	***	***	***	***	**	NS
L x D		NS	NS	NS	NS	NS	NS	NS
S x D		NS	NS	NS	NS	NS	NS	NS
L x S x D		NS	NS	NS	NS	NS	NS	NS

NS = Non Significant; * = P < 0.05 ; ** = P < 0.01 ; *** = P < 0.001

Only the interaction of line x sex was significant at 15 and 30 days of age. The significant interaction was found in primary and tail feather lengths (15 days of age) and primary, secondary, tail, back and breast feather lengths (30 days of age).

At 15 days of age, the fast feathering line had greater body weight than the slow feathering line on all diets, but at 30 days of age this was reversed. Males were always heavier than females. The fast feathering line had longer feathers than the slow feathering line for all feathers measured at both ages. Females had better feathering than males at 15 days of age. At 30 days of age, the fast feathering males had longer primary feathers than the fast feathering females.

The diets which gave the maximum response in body weight and feathering are presented in Table 5.10.

At 15 days of age, the birds of fast and slow feathering lines fed diet C had greater body weights than those fed the other diets. Generally, fast feathering males fed diet D, fast feathering females fed diet C or D, slow feathering males fed diet D and slow feathering females fed diet E had better feathering than those fed the other diets.

At 30 days of age, fast and slow feathering lines fed diet B (male) or diet C (female) had greater body weight than those fed the other diets. In general, fast males fed diet D, fast females fed diet C, slow males fed diet D or E and slow females fed diet E had better feathering than those fed the other diets.

Table 5.10. Diets giving maximum response in body weight and feather lengths (see material and methods for description of diets)

Line	Fast				Slow			
Age (days)	15		30		15		30	
Sex	M	F	M	F	M	F	M	F
* Body Weight	B	C	B	C	C	C	B	C
* Feather Type:								
- Primary	D	C	D	C	D	E	D	E
- Secondary	D	C	D	C	D	E	D	E
- Tail	D	D	D	D	E	E	C	E
- Breast	C	D	D	C	A	A	E	E
- Back	C	D	D	C	D	E	D	E
- Thigh	D	C	D	D	A	E	E	E

M = Male; F = Female

V.4. DISCUSSION

The stock used in this study were the progeny of the third generation of lines divergently selected for fast and slow feathering. Since cystine is the major sulphur bearing amino acid in feathers, the differences in the rate of feathering between fast and slow feathering lines is expected to have an influence on cystine requirement. Therefore, in this experiment, the diets were formulated to contain the same levels of methionine, protein and ME, but cystine levels ranged from about 80 to 120 per cent of published requirements. The diets were produced so that the cystine would the first limiting amino acid and thus responses would be due to cystine intake

Quadratic regression equations used to identify the cystine intake giving maximum response. These equations showed that there was an effect of cystine intake on body weight of fast feathering males and females of fast and slow feathering lines, but not in the slow feathering males. While the response of feather lengths to cystine intake was more obvious in the slow feathering females. It also seems that a higher level of cystine than used in this experiment was needed to demonstrate a level for maximum response for the slow feathering females.

The discussion of the results will be more specific about feed intake, cystine intake, feed conversion ratio (FCR), body weight and feather growth, as affected by cystine level in the diets of those birds during periods I (0-15 days of age) and period II (16-30 days of age). As

in experiment 1 (Chapter IV), the ratio of feather length to body weight was calculated and will be discussed.

V.4.1. Feed Intake, Cystine Intake and Feed Conversion Ratio

During period I, the increased cystine level in the diet resulted in increasing cumulative cystine intake but cumulative feed intake was not different between diets. This result is in agreement with Wheeler and Latshaw (1981) who reported that the increased amounts of cystine supplementation improved growth without an equal change in feed intake. During period II, generally, the birds fed a lower cystine diet showed lower cumulative cystine intake and a higher cumulative feed intake. In this case, it seems the birds ate more feed to try to make up the cystine deficiency in the diet.

In the period I the birds fed diet C (3.5 g Cystine/kg; 8.1 g SAA/kg) had a better FCR than birds fed lower or higher levels. However, the improvement in FCR was 0.038, 0.069, 0.044 and 0.025 for each g/kg increase in cystine content for fast males, fast females, slow males and slow females, respectively. During period II, apparently the males of fast and slow feathering lines required more cystine (3.8 g Cystine; 7.8 g SAA/kg) than females (3.0 g cystine/kg; 7.0 g SAA/kg) for the best FCR. The improvement in FCR was 0.257, 0.157, 0.143 and 0.06 for each g/kg increase in cystine content for fast males, fast females, slow males and slow females, respectively. It seems that as

cystine levels were increased in the diets, more effective protein became available for growth. The males required higher protein levels than females for their growth, where as was indicated during period II the males grew faster than females. Therefore the males required a higher cystine to get a better FCR than the females.

V.4.2. Body Weight

Generally, fast and slow feathering males fed diet B (period I= 3.1 g cystine/kg; 7.7 g SAA/kg; period II= 2.7 g cystine/kg; 6.7 g SAA/kg) achieved maximum body weight. However, the slow feathering males required a higher cystine level (3.5 g cystine/kg) during period I. While the females seem to require a higher cystine level in the diet than the males (period I= 3.5 g cystine/kg; 8.1 g SAA/kg; period II= 3.0 g cystine/kg; 7.0 g SAA/kg) for maximum growth.

V.4.3. Feather Lengths

The fast feathering line had longer feathers than the slow feathering line for all feathers measured at 15 and 30 days of age. At 15 days of age, the females had longer feathers and higher scores than males, but at 30 days of age the males had longer primary feathers than females.

During period I, the fast and slow feathering lines required 3.9 g cystine/kg (8.5 g SAA/kg) for their feather growth. However, the females of slow feathering line

required a higher level of cystine (4.3 g cystine/kg) than the others. Since in the slow feathering line, the females apparently had longer feathers than males, therefore the females required higher cystine for their feather growth. This result is in agreement with Engler *et al.* (1985) who indicated that female broilers are able to use more cystine than males.

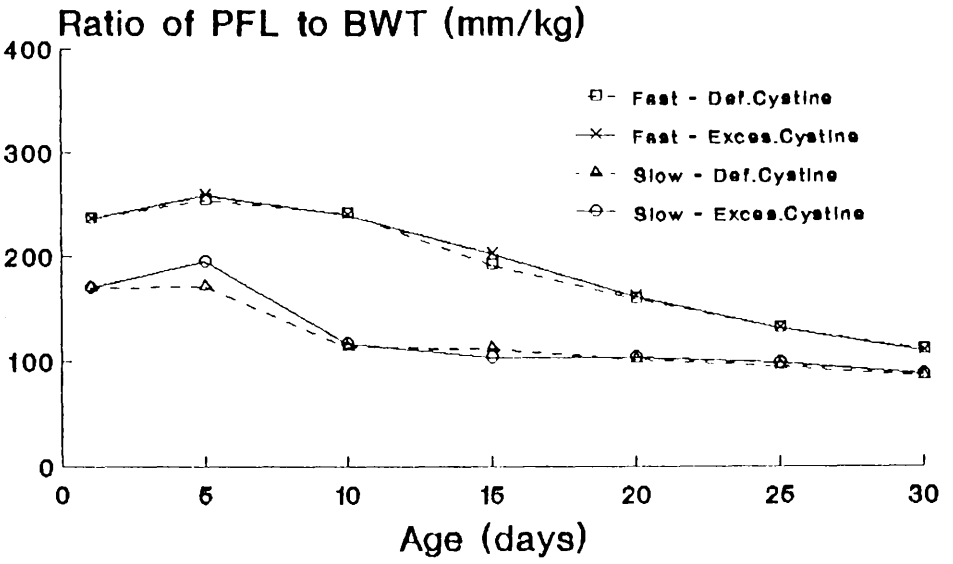
During period II, in general, slow feathering females required a higher cystine level than fast females. However, the males of fast feathering line required slightly more cystine than females, but the males of slow feathering line required less cystine than females.

V.4.4. The Ratio of Feather Length to Body Weight

The same reason with in the experiment 1 (Chapter IV), the ratio of feather length to body weight (F:B) was calculated to remove the effect of body weight and thus allow independent differences between line and sex of feather growth to be observed.

The F:B ratio of the wing, tail, back, breast and thigh feathers were calculated and the results are shown in Figs. 5.6-5.11 and present the effects of line and diet within sex. The F:B ratio of primary feathers decreases due to age at the extremes of the levels of cystine (deficient and excess cystine). The decrease of this ratio was more obvious in the fast line. The F:B ratio of secondary feathers also decreased due to age in fast feathering line, in both sexes

Male



Female

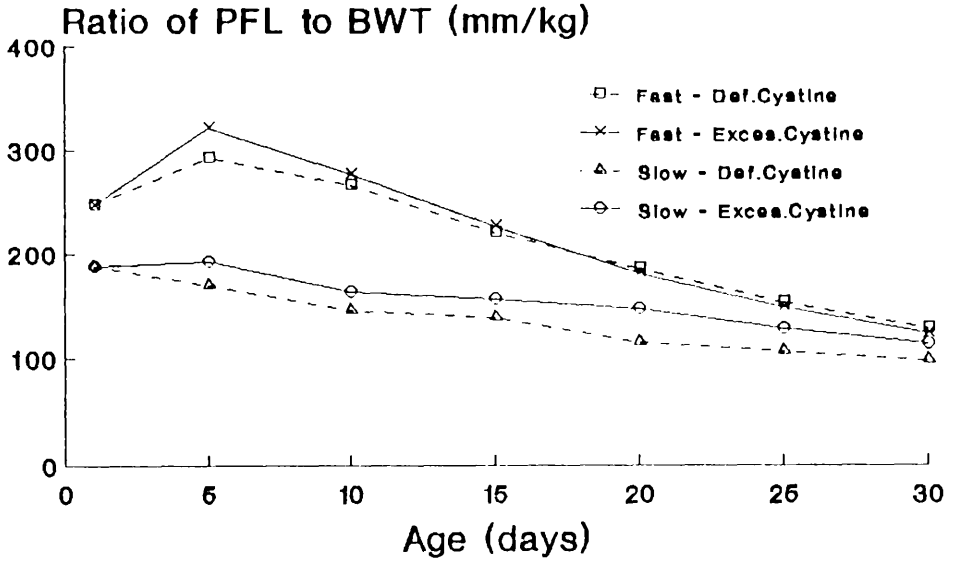
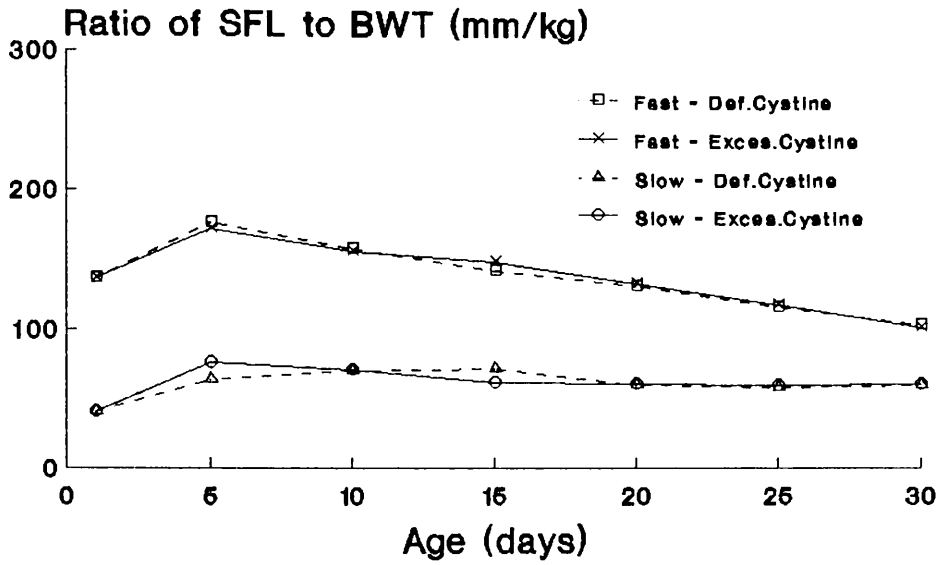


Figure 5.6. Effect of deficient and excessive cystine diets on the ratio of primary feather length to body weight

Male



Female

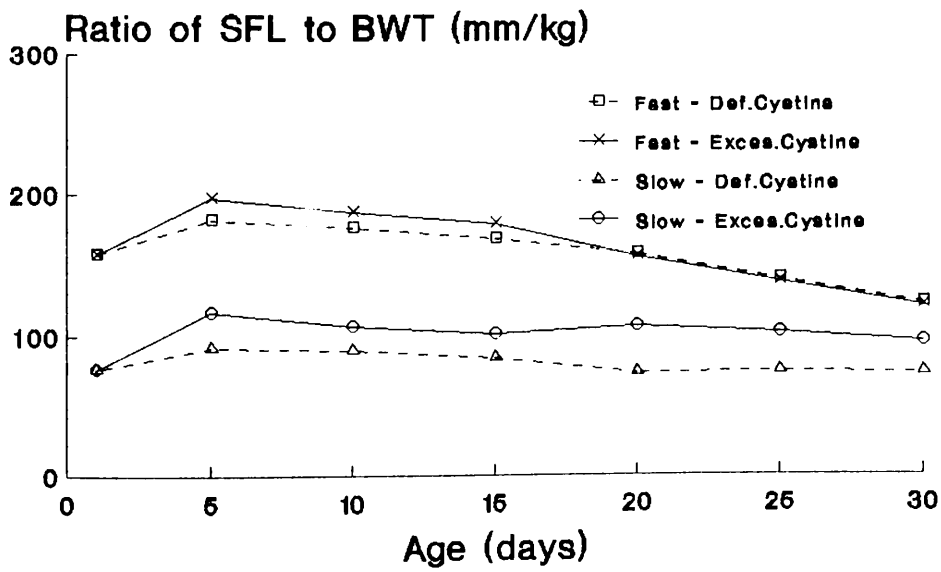


Figure 5.7. Effect of deficient and excessive cystine diets on the ratio of secondary feather length to body weight

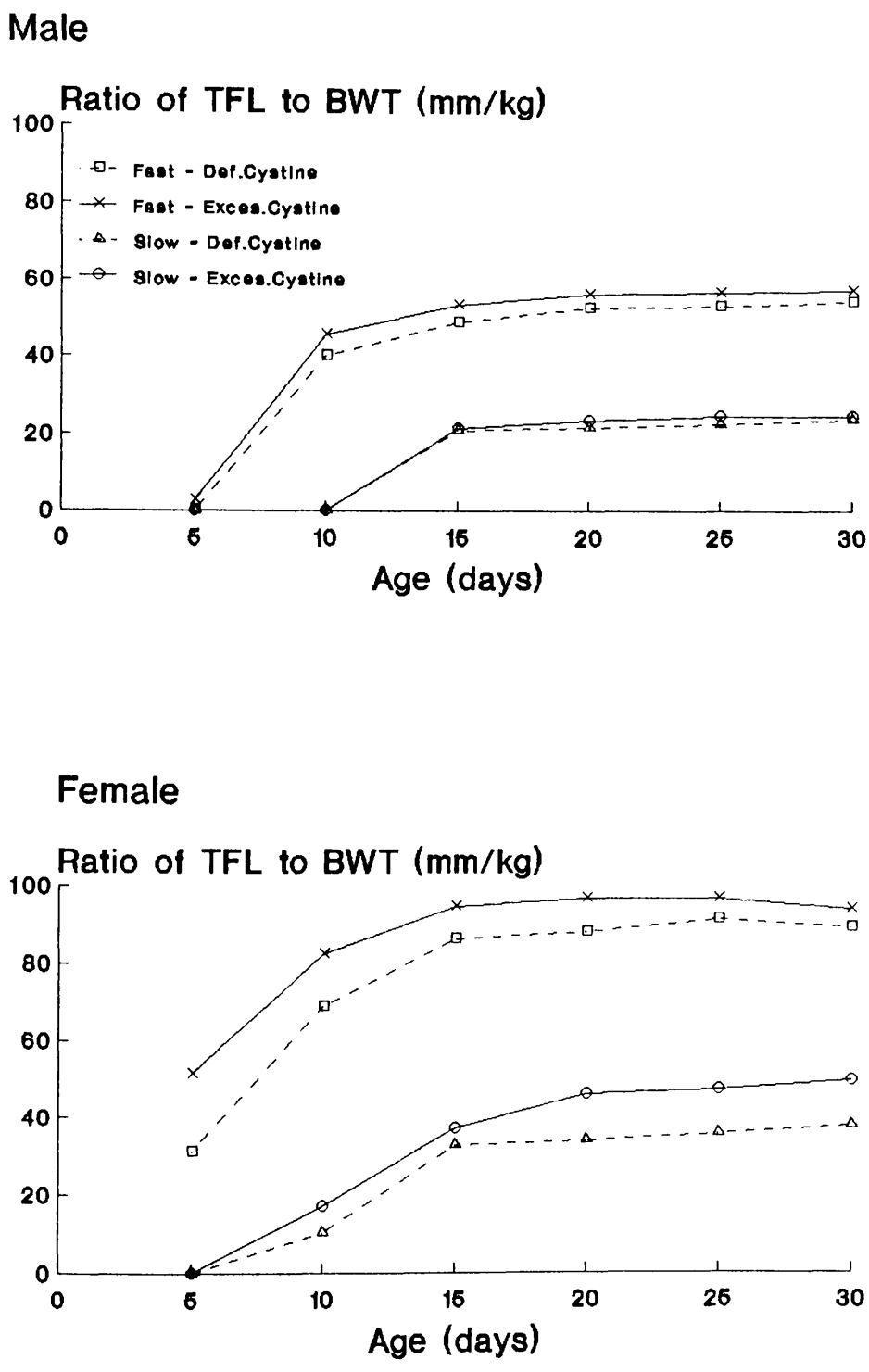
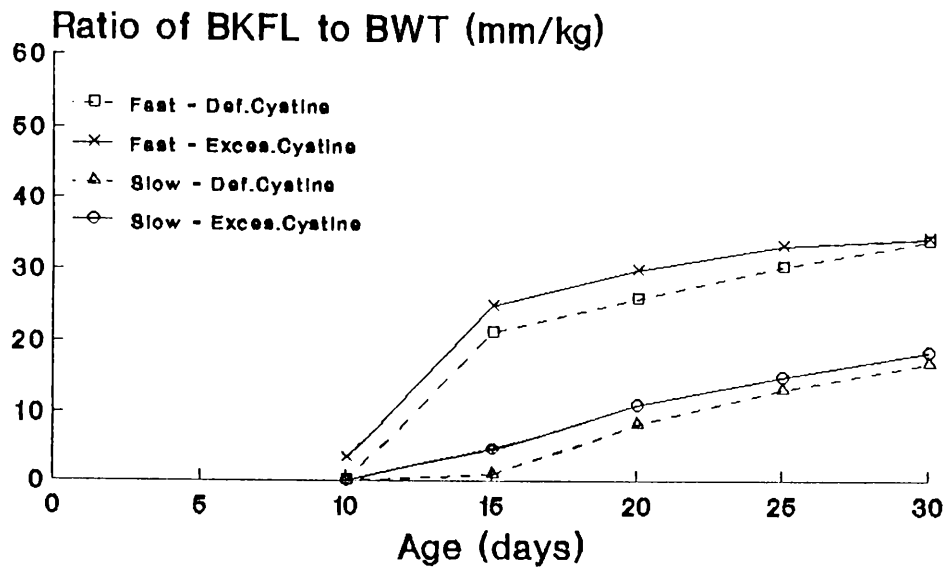


Figure 5.8. Effect of deficient and excessive cystine diets on the ratio of tail feather length to body weight

Male



Female

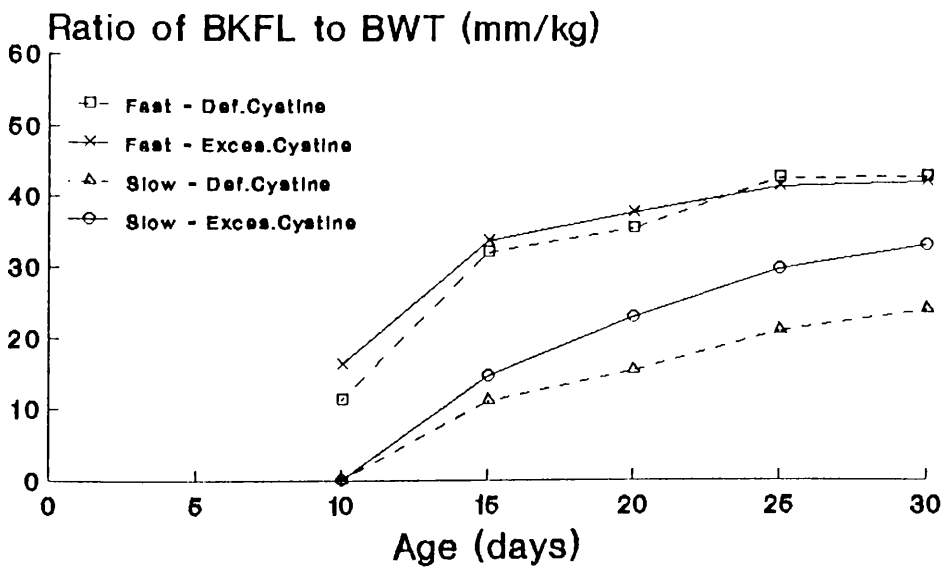
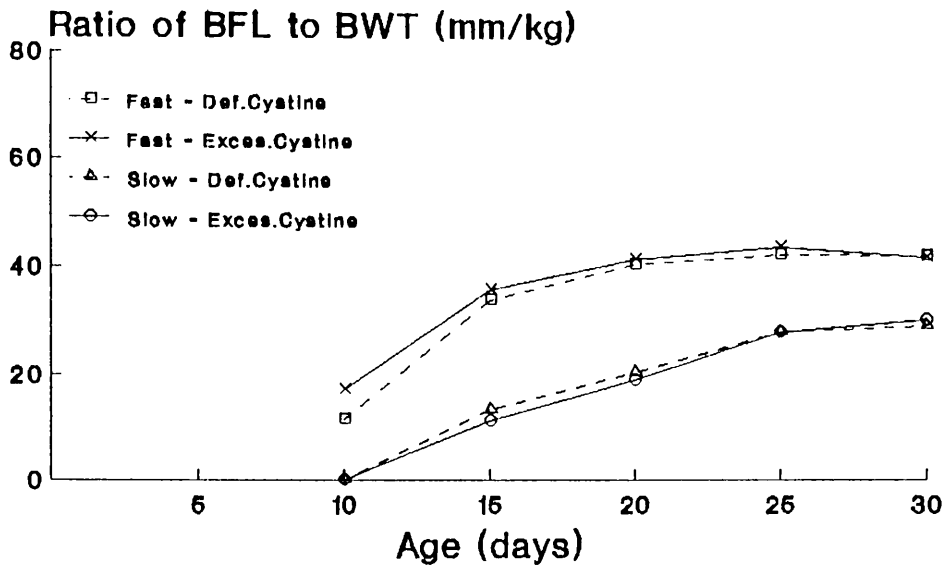


Figure 5.9. Effect of deficient and excessive cystine diets on the ratio of back feather length to body weight

Male



Female

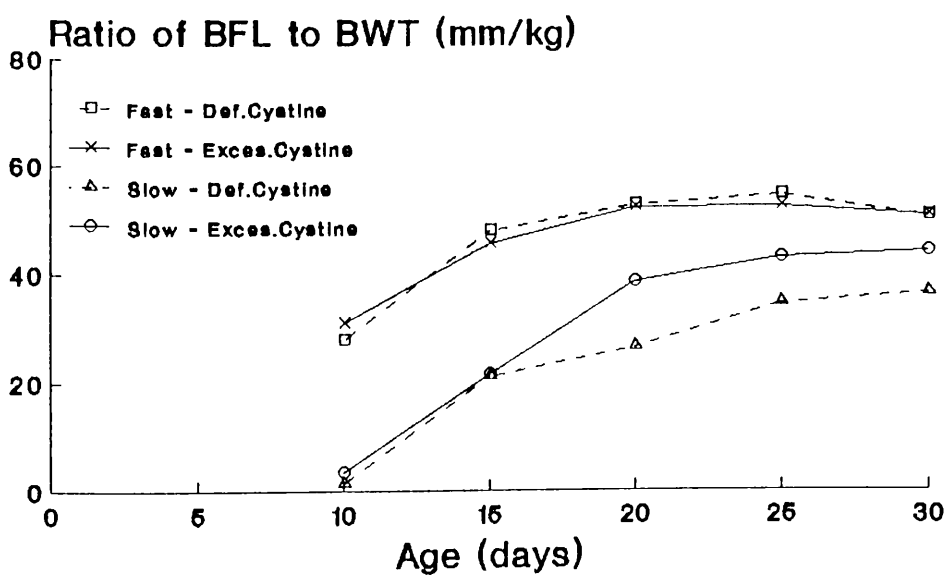
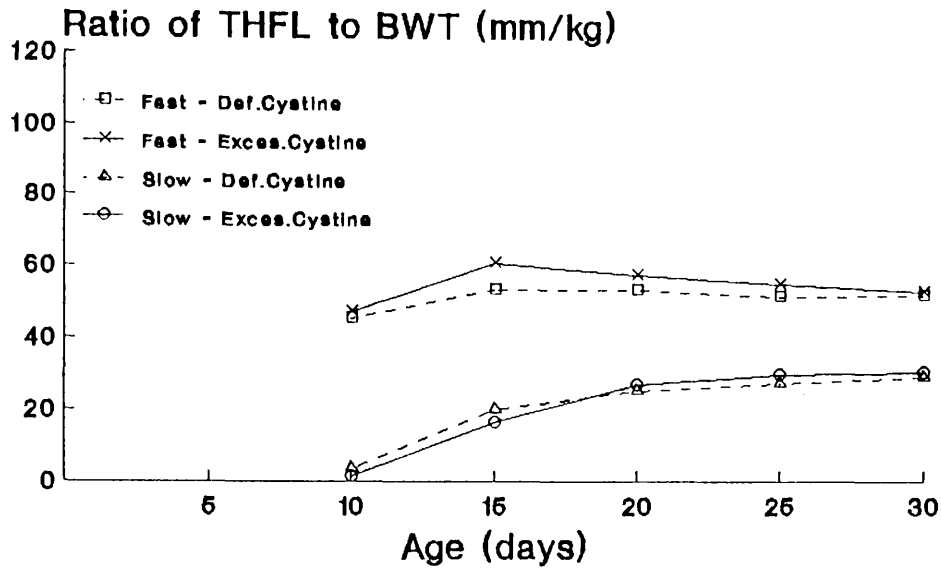


Figure 5.10. Effect of deficient and excessive cystine diets on the ratio of breast feather length to body weight

Male



Female

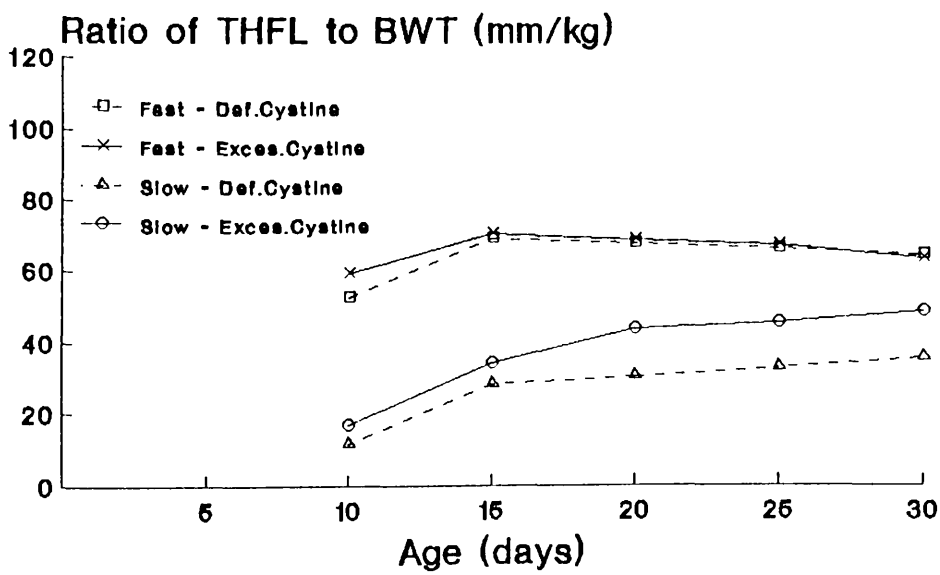


Figure 5.11. Effect of deficient and excessive cystine diets on the ratio of thigh feather length to body weight

and in the two different levels of cystine. But for the slow feathering line the decreasing F:B ratio of secondary feathers was not so obvious. It seems that the growth of primary and secondary feathers of the slow line proceeds almost at the same rate as the body. The F:B ratio of tail feathers increases due to age in both lines and both sexes. The F:B ratio of back feathers and of breast feathers also increased due to age in both lines and both sexes, while the F:B ratio of thigh feathers increases due to age in slow line, in both sexes and in the two different levels of cystine. When F:B ratio increases with age this indicates that feather growth is relatively faster than the body as a whole and a feather type or tract is relatively more important later in development of a chicken.

The effect of diet is more pronounced in the females of the slow line, for which the high cystine diet accelerated their feather growth. However, the effect of diet on feather growth in fast line was seen at an earlier age. It seems that the effect of the feathering genotype in the fast line in both sexes and in the slow males was greater than the effect of cystine content of the diet.

Since the high cystine diet gave a greater F:B ratio than the deficient cystine diet in the slow females, thus a good quality diet will produce chickens with better feathering. But in the slow males, the high cystine diet was only able to increase the F:B ratio of back feathers. It is possible that the feather growth in slow males was more effected by genetic than nutrition factors.

It is concluded that for better FCR fast and slow feathering lines required 3.5 g cystine/kg diets during period I (0-15 days of age). During period II (16-30 days of age), the males of fast and slow lines required a higher cystine (3.8 g/kg) than in the females (3.0 g/kg). It seems that during the first two weeks of the birds' life, the fast and slow feathering lines required a higher cystine in the diets for their feather growth than FCR or body weight. These results are supported by Rasheld and Oldfield (1964) and Moran (1981) who reported that animal performance can be maximised at a lower cystine level than is necessary to maximise feather development.

The cystine requirement of fast and slow feathering lines for maximum growth of body and feathers are summarised in Table 5.11. The cystine requirement in this study was found to be higher than the published cystine requirement of broiler chickens.

Table 5.11. Digestible cystine requirement of fast and slow feathering lines (g/kg)

Line	Fast				Slow			
Age (days)	0 - 15		16 - 30		0 - 15		16 - 30	
Sex	M	F	M	F	M	F	M	F
Body Weight	3.1	3.5	2.7	3.0	3.5	3.5	2.7	3.0
Feather Growth	3.9	3.9	3.4	3.0	3.9	4.3	3.4	3.8

The published digestible cystine requirement of broiler chikens: 0-15 days old= 3.4 g cystine/kg; 16-30 days old= 3.0 g cystine/kg (see Table 5.4).

CHAPTER VI. EXPERIMENT 3:

FEATHER GROWTH OF BROILER CHICKENS

VI.1. INTRODUCTION

Feathers are the main characteristic of birds to make them different from other vertebrates. They are important for insulation against cold, for protection from the elements, to prevent skin injury and for the production of high quality broiler carcasses. The feathers play a vital role in conserving heat and so have an influence on economic returns through feed efficiency in the production of poultry meat. Many breeding programmes have incorporated the objective of increasing feather growth rate with the objective to improve feed efficiency, body weight and to minimise pin feathers on the dressed carcass of broilers. Therefore high quality broilers with an attractive carcass at the point of sale will be obtained.

The fact that feather growth is affected by genetics, nutrition, temperature, and hormones was recognised more than 50 years ago (Gericke and Platt, 1932; Radi and Warren, 1938). Observation on the growth of feathers has shown that there are two major loci affecting feathering, k^+ and t^+. The k series, which produces fast and slow feathering sex-linked genes, is exploited commercially for feather sexing in white feathering layer and broiler stock.

Feathering is normally rapid in most common commercial strains of poultry so that by the end of a 3-4 week brooding period feather cover is sufficient to enable the bird to be independent of brooder heat. Therefore it is sensible to focus for an area of investigation the observation of feather growth during this stage of development. The objective of this study was to obtain more information in feather growth of fast and slow feather lines in both sexes during the first 30 days of their life. Beside that there is a lack of information about the emergence of feathers and the subsequent growth of the tracts in a modern broiler stock.

VI.2. MATERIALS AND METHODS

VI.2.1. Experimental Design

The experimental design used was a 2 x 2 factorial with male and female broilers of the fast and slow feathering lines. The data were collected from 14 chickens from each sex and was carried out from hatching time to 30 days of age, with two-day intervals for feather and ten day intervals for body weight measurements.

VI.2.2. Birds and Management

The 28 male and 28 female broiler chicks of fast and slow feathering lines were obtained by artificial insemination using pooled semen of males. The chicks were

progeny of the third generation of the selection lines. After hatching the chicks were wing banded, weighed and the primary and secondary feather lengths were measured. The chicks were transported to the house and put into one floor pen (300 x 360 cm).

Brooding heat was provided by gas brooders. The minimum and maximum temperatures were recorded every morning, using a Minimum-Maximum dry-bulb thermometer. The average temperature during the first week was 30.5^{o}C, 21^{o}C during the next 14 days and thereafter 19^{o}C. The feeding and drinking space for each bird were 6.5 cm/bird and 7.0 cm/bird respectively.

VI.2.3. Diets

For the first 14 days, the birds were given a commercial starter diet (CP= 250 g/kg; ME= 13 MJ/kg). Thereafter, up to 30 days of age, they were given a commercial grower diet (CP= 220 g/kg; ME= 13 MJ/kg).

VI.2.4. Recording Procedure

a. Feather Growth

Every two days from 0 to 30 days of age, the feather tract observations and feather measurements were carried out.

a.1. Recording the Time of the Appearance of the Feathers

The feather tracts observed were (common name/anatomical name) :

- Head /capital
- Hackles /cervical
- Cape /interscapular
- Back /dorsopelvic
- Shoulder /humeral
- Thigh /femoral
- Leg /crural
- Breast /pectoral
- Ventral /sternal and abdominal

In addition to these eight tracts, the primary and secondary wing feathers and tail feather were also observed. The location of these feather tracts can be seen in Fig. 6.1.

a.2. Number of Feathers Emerged from Their Sheaths

The recording of the number of feathers in a tract was carried out only in cape, shoulder, thigh, and breast tracts, and in primary and secondary wing feathers. The recording continued in these tracts until about 50 per cent of the feathers had emerged from their sheaths, except in the case of the wing feathers where all feathers which emerged were recorded.

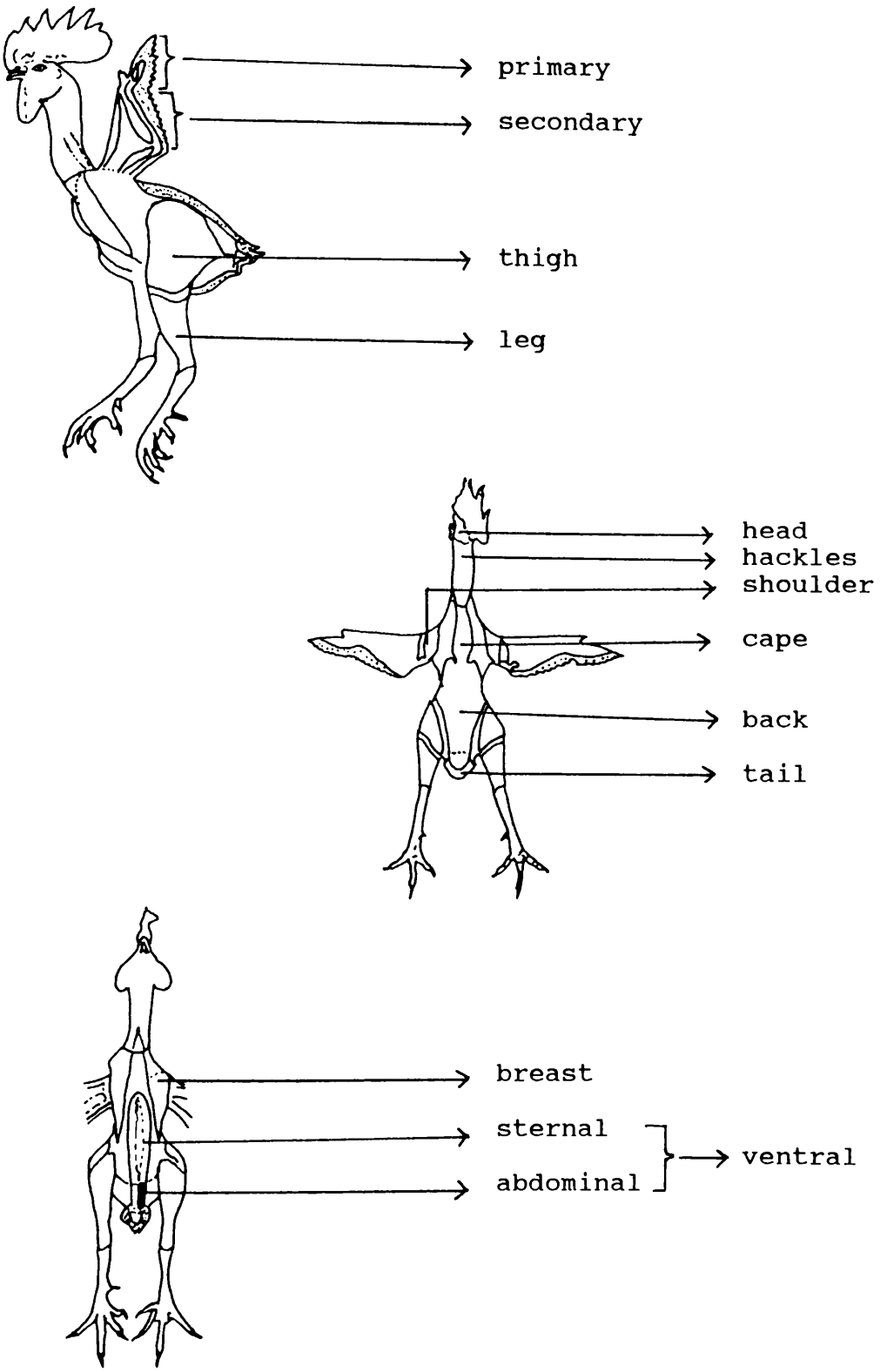


Figure 6.1. Location of the feather tracts (modified after Herremans, 1986)

a.3. Feather Lengths

Feather length measurements were carried out only for wing, tail, cape, back, breast and ventral feathers. The methods for measuring some of those feathers were mentioned in Chapter III. The cape feathers were measured from the base of the pin feather to the farthest point of emergence. The measurement of ventral feathers was carried out in the sternal region, not in the abdominal region. One feather in the centre of the right part of sternal region was measured from the base of the pin feather to the farthest point of emergence.

a.4. Photography of Birds

Photographs were taken of birds from each sex and line. Birds which were selected represented the extremes of the feather growth for each set of 14 birds at 10, 20 and 30 days of age.

b. Body Weight

The birds were weighed individually using a Mettler PM6000 balance every ten days from hatching to 30 days of age.

VI.2.4. Statistical Analysis

Data was analysed by analysis of variance using Minitab and Genstat V computer packages. The differences between female and male in feathers appearance and the number of feathers out of the sheaths were tested using Chi-Square Test.

VI.3. RESULTS

VI.3.1. The Appearance of Feathers

All of the primary and secondary feathers appeared at hatching in both lines and both sexes. The order and the time of appearance of feathers in the other tracts are shown in Table 6.1. From this observation, all feathers of the fast line emerged earlier than those of the slow feathering line. Based on the Chi-Square test, the appearance of feathers were not different in females and males of the fast line. But a sex difference in the slow line was shown in tail feather, since more females had tail feathers earlier than males.

VI.3.2. The Feathers Emerged from Their Sheaths

The number of feathers emerged from their sheaths in some feather tracts are presented in Figs. 6.2, 6.3, 6.4, 6.5, 6.6 and 6.7. Figures 6.2 and 6.3 indicate that the number of primary and secondary feathers out of sheath (PFOS

Table 6.1. Time and order of appearance of feathers in different tracts in fast and slow feathering lines

Tracts	Lines	Sex	Percentage distribution of birds on basis of age at time of appearance of tract *											
			Days											
			0	2	4	6	8	10	12	14	16	18	20	22
Primary	Fast	F	100											
		M	100											
	Slow	F	100											
		M	100											
Secondary	Fast	F	100											
		M	100											
	Slow	F	100											
		M	100											
Shoulder	Fast	F	.....			100								
		M	.....			79	21							
	Slow	F	.....			57	43							
		M	.....			21	43	29	7					
Tail	Fast	F	.....			86	7	7						
		M	.....			29	28	43						
	Slow	F	.....			14	15	42	29					
		M	.....					14	65	21				
Thigh	Fast	F	.....				93	7						
		M	.....				57	43						
	Slow	F	.....					57	36	7				
		M	.....					21	65	14				
Cape	Fast	F	.....				14	86						
		M	.....					100						
	Slow	F	.....					29	21	50				
		M	.....							36	43	7	0	7

Note: * Percentage of 14 birds
F = Female; M = Male

(.....continued)

Table 6.1. (continued)

Tracts	Lines	Sex	Percentage distribution of birds on basis of age at time of appearance of tract *											
			Days											
			0	2	4	6	8	10	12	14	16	18	20	22
Breast	Fast	F						100						
		M						100						
	Slow	F						50	29	21				
		M						14	50	36				
Back	Fast	F						100						
		M						64	36					
	Slow	F						29	42	22	7			
		M							29	57	7	7		
Leg	Fast	F							100					
		M							100					
	Slow	F							21	79				
		M								93	7			
Hackles	Fast	F							100					
		M							93	7				
	Slow	F							43	21	36			
		M							7	86	7			
Ventral	Fast	F							86	14				
		M							93	7				
	Slow	F								57	43			
		M								64	22	14		
Head	Fast	F							43	57				
		M								93	7			
	Slow	F								64	36			
		M								14	79	7		

Note: * Percentage of 14 birds
F = Female; M = Male

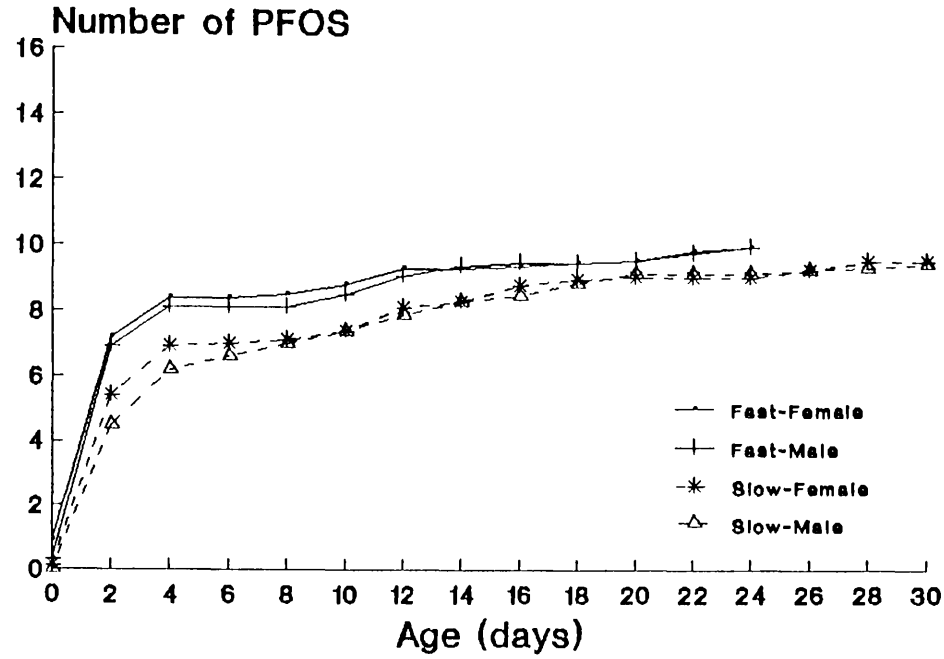


Figure 6.2. Effects of age, line and sex on the number of primary feathers out of sheaths (PFOS)

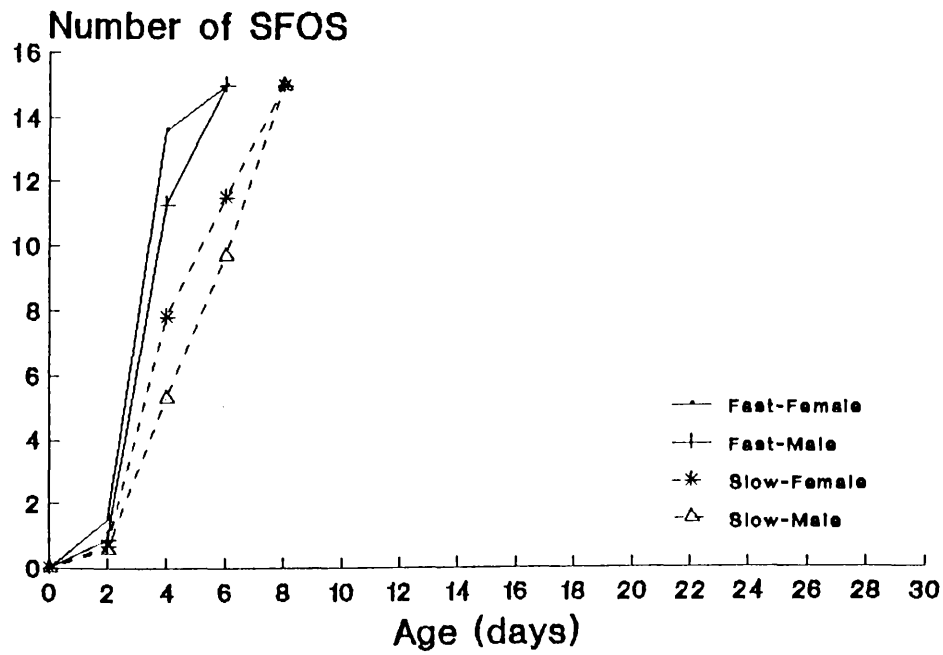


Figure 6.3. Effects of age, line and sex on the number of secondary feathers out of sheaths (SFOS)

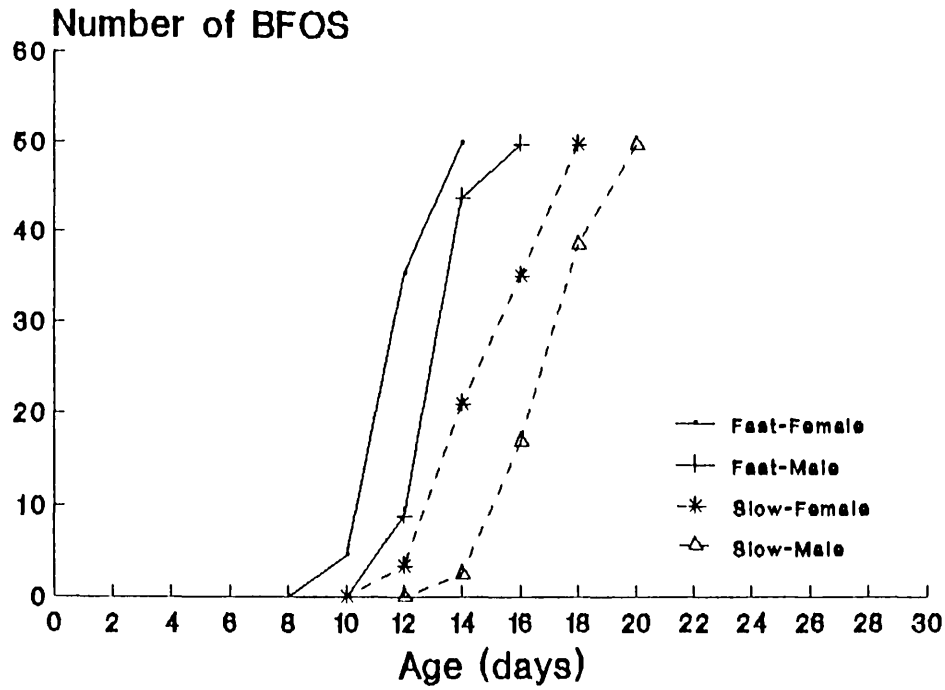


Figure 6.4. Effects of age, line and sex on the number of breast feathers out of sheaths (BFOS)

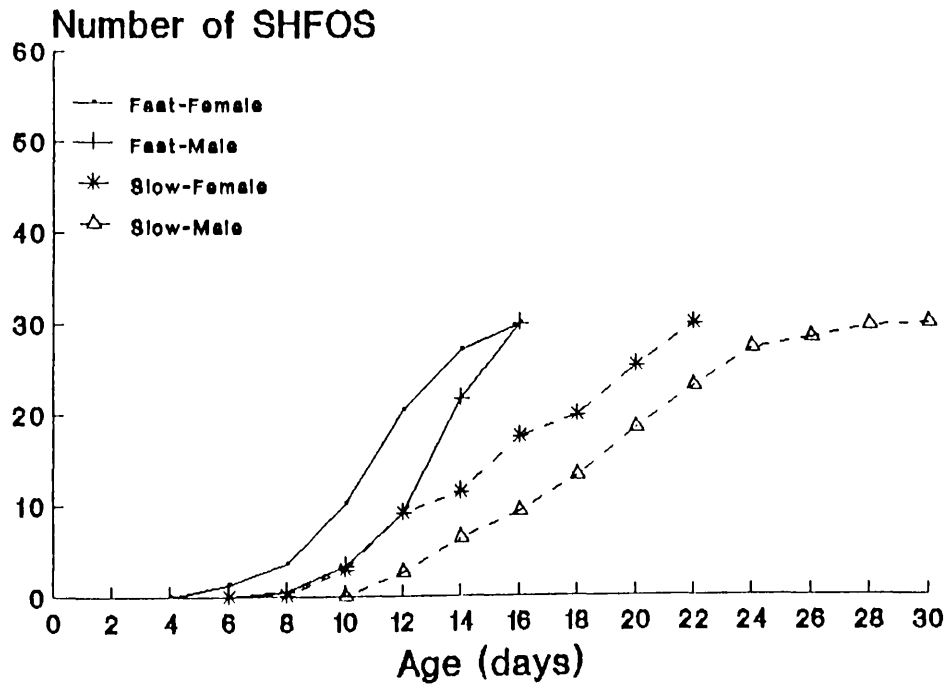


Figure 6.5. Effects of age, line and sex on the number of shoulder feathers out of sheaths (SHFOS)

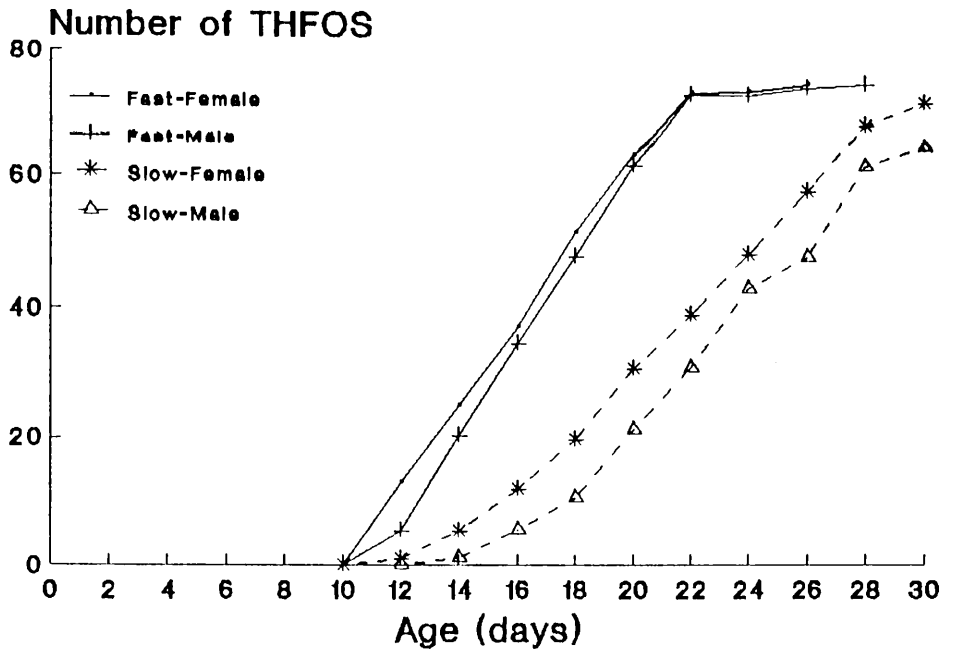


Figure 6.6. Effects of age, line and sex on the number of thigh feathers out of sheaths (THFOS)

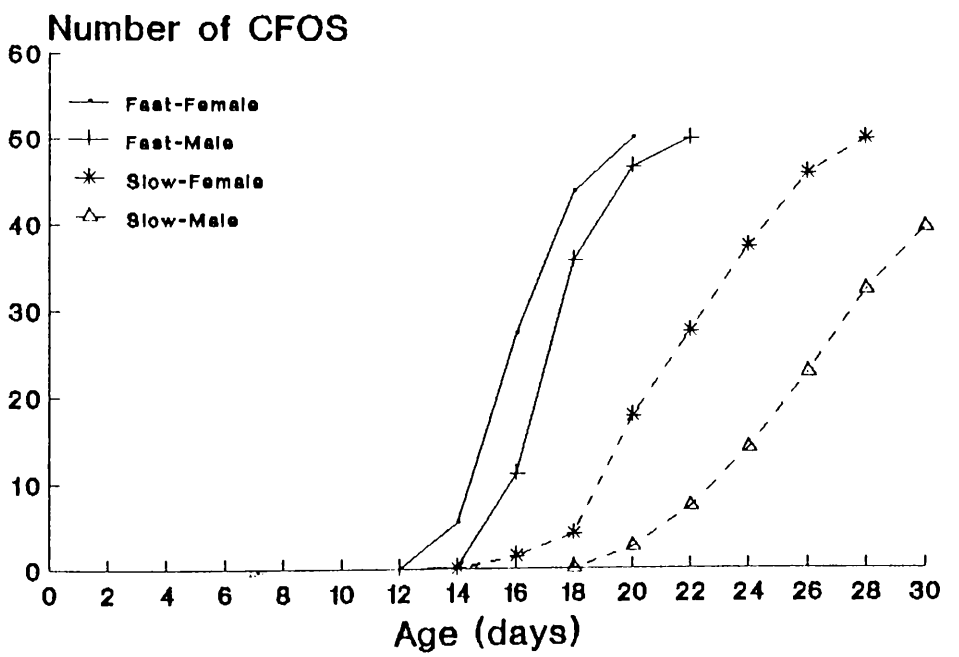


Figure 6.7. Effects of age, line and sex on the number of cape feathers out of sheaths (CFOS)

and SFOS) show a small difference between lines and an even smaller sex difference. The effect of divergent selection in these feathers is not so obvious, while Figs. 6.4-6.7 show that fast line had more feathers and emerged earlier from their sheaths than those in the slow feathering line. The Chi-Square test demonstrated that males had greater differences of breast and cape feathers out of sheaths between the fast and slow lines than the females ($P<0.05$). In this case, it appears that divergent selection has had a more pronounced effect on males than females.

VI.3.3. Primary and Secondary Feathers

The primary and secondary feathers growth from 0 to 30 days of age are shown in Figs. 6.8 and 6.9. The primary and secondary feathers of the fast line were longer than those of the slow line from hatching to 30 days of age. For the fast line, the primary feathers from hatching to 12 days of age and secondary feathers from 6 to 24 days of age were longer in females than in males. However, males had longer primary and secondary feathers than females at about 22 to 30 days of age and 28 to 30 days of age respectively. For the slow line, the primary feathers from 8 to 30 days of age and secondary feathers from 2 to 30 days of age were longer in females than in males. The difference in these feather length gains between the two lines were most prominently shown at about 2 to 10 days of age for primary feathers and from 2 to 20 days of age for secondary feathers, since the

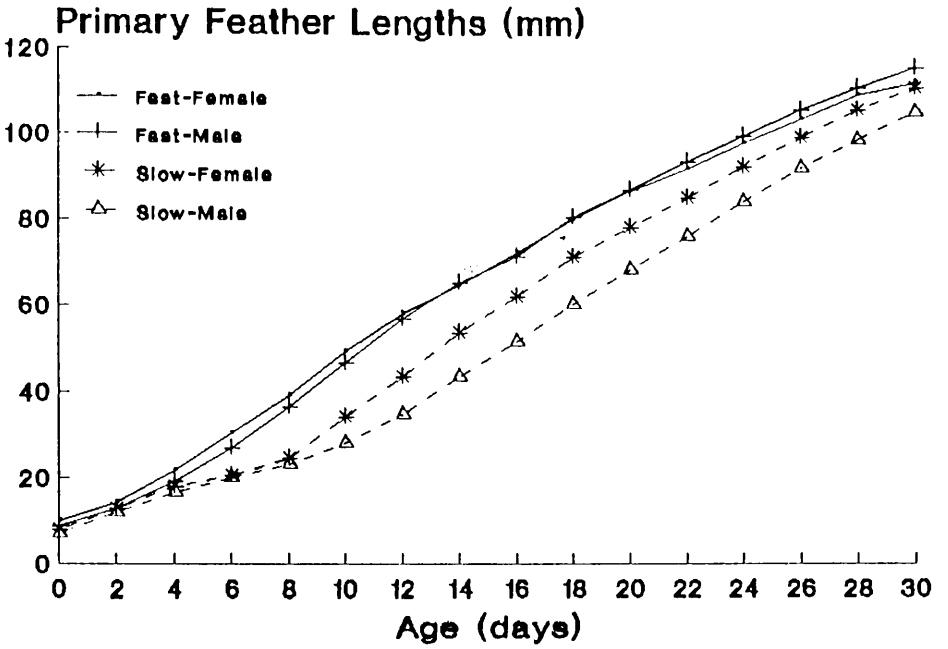


Figure 6.8. Effects of age, line and sex on primary feather lengths

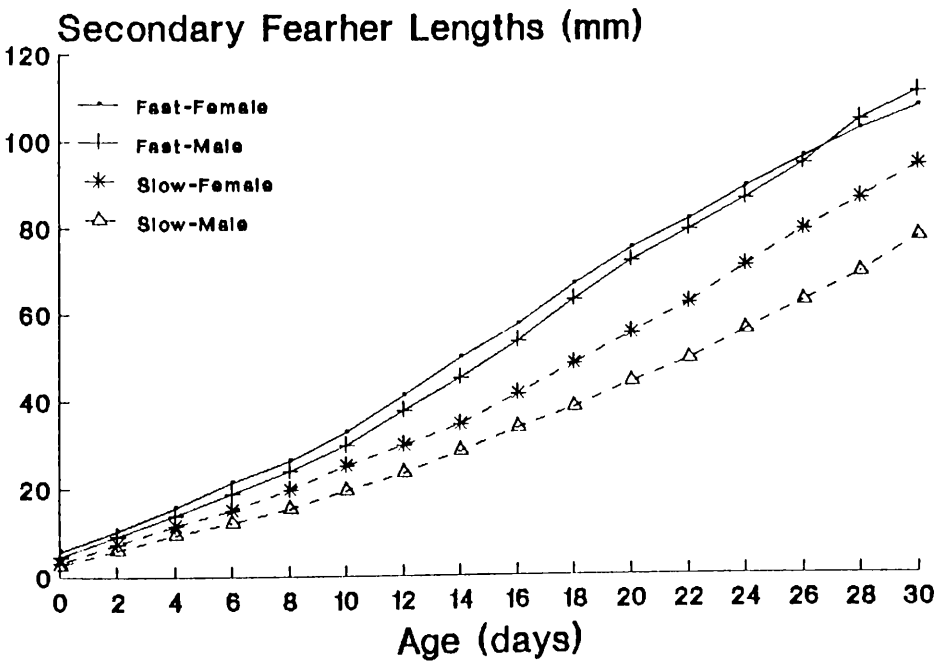


Figure 6.9. Effects of age, line and sex on secondary feather lengths

feathers of the fast line were growing faster than those of slow line.

There were no significant differences in primary feather length gain every 2 days between both lines and both sexes. The average rate of primary feather growth during 30 days was about 7 mm/2 days. While the average of the secondary feather length gain was 6.8, 7.2, 6.1 and 5.0 mm/2 days for fast female, fast male, slow female and slow male, respectively.

VI.3.4. Tail Feathers

The tail feather growth can be seen in Fig. 6.10. By 6 days of age, the tail feathers of the fast line had appeared, but the slow line birds did not have a tail yet. The prominent difference in those feathers between the sexes in both lines was shown at about 8 to 30 days of age. In general, the fast line had longer tail feathers than the slow line and females had longer feathers than males. The tail feather length gain was 5.3, 4.1, 3.1 and 2.2 mm/2 days for fast female, fast male, slow female and slow male, respectively.

VI.3.5. Back and Breast Feathers

The back and breast feather growth are presented in Figs. 6.11 and 6.12. The back and breast feathers appeared at about 10 days of age, except for back feathers in slow

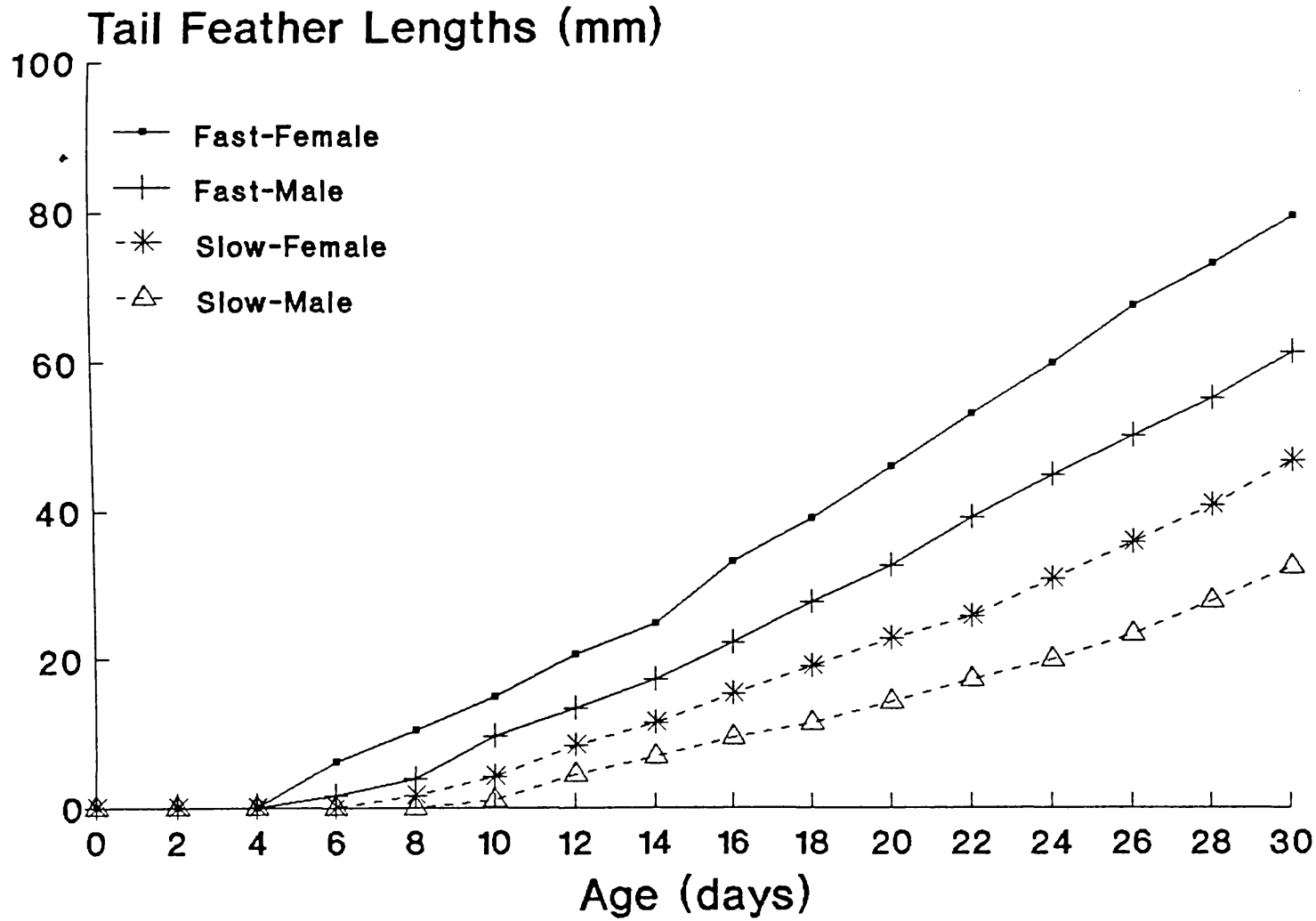


Figure 6.10. Effects of age, line and sex on tail feather lengths.

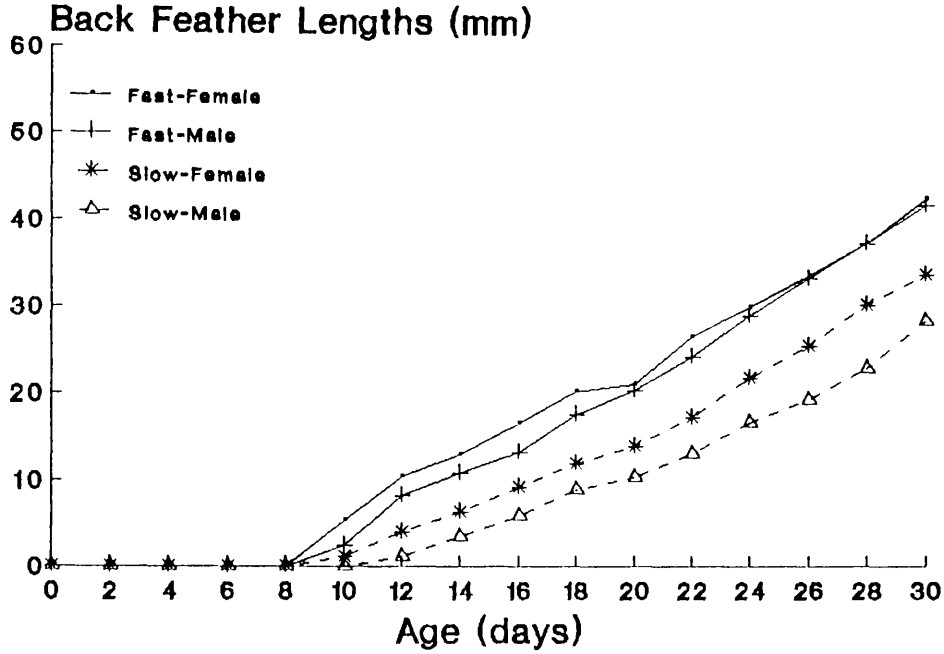


Figure 6.11. Effects of age, line and sex on back feather lengths

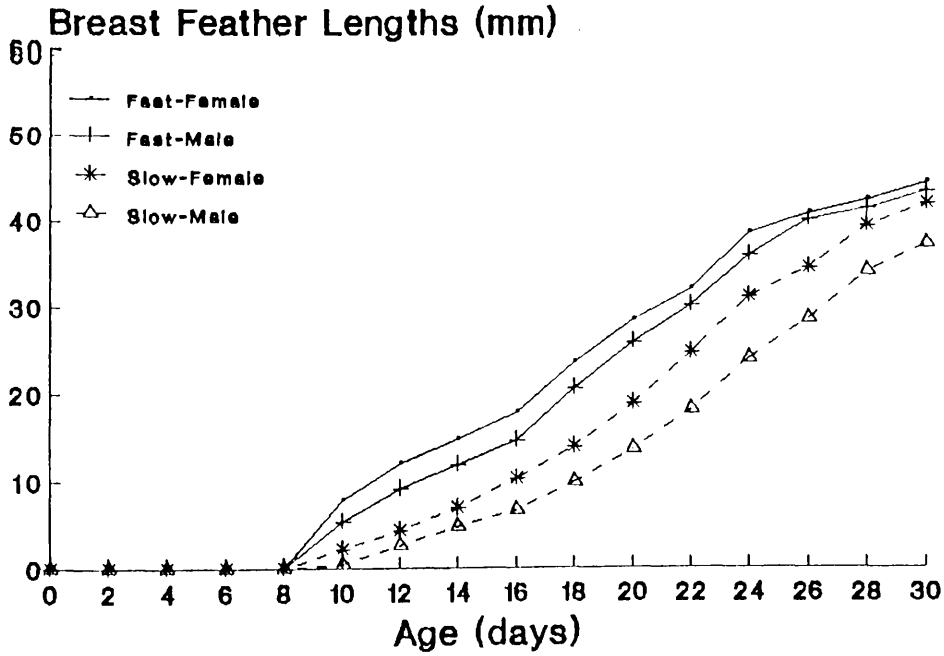


Figure 6.12. Effects of age, line and sex on breast feather lengths

males. From 10 to 30 days of age, the fast line had longer back and breast feathers than the slow line. During these ages, for the slow line, these feathers were longer in females than in males. For the fast line, the back and breast feathers were longer in females than in males at about 10 to 24 days of age. After this age the difference was not significant.

The feather length gain in the fast line appeared greater than in the slow line between 8 to 12 days of age for back feathers and between 8 to 18 days of age for breast feathers. There were no differences in back and breast feather length gain between males and females in both lines. The back feather length gain was about 3 and 2 mm/2 days for fast and slow feathering lines, respectively. The average of breast feather length gain was about 3.0 and 2.7 mm/2 days for fast and slow feathering lines, respectively.

VI.3.6. Cape and Ventral Feathers

The cape and ventral feather growth are shown in Figs. 6.13 and 6.14. The appearance of these feathers could be seen at about 14 days of age. The fast feathering line had longer cape and ventral feathers than the slow feathering line from 14 to 30 days of age. For the fast line, the cape and ventral feathers were found to be longer in females than in males at about 14 to 26 days of age and 14 to 28 days of age, respectively. In the slow line, these feathers were also found to be longer in females than in males from 14 to

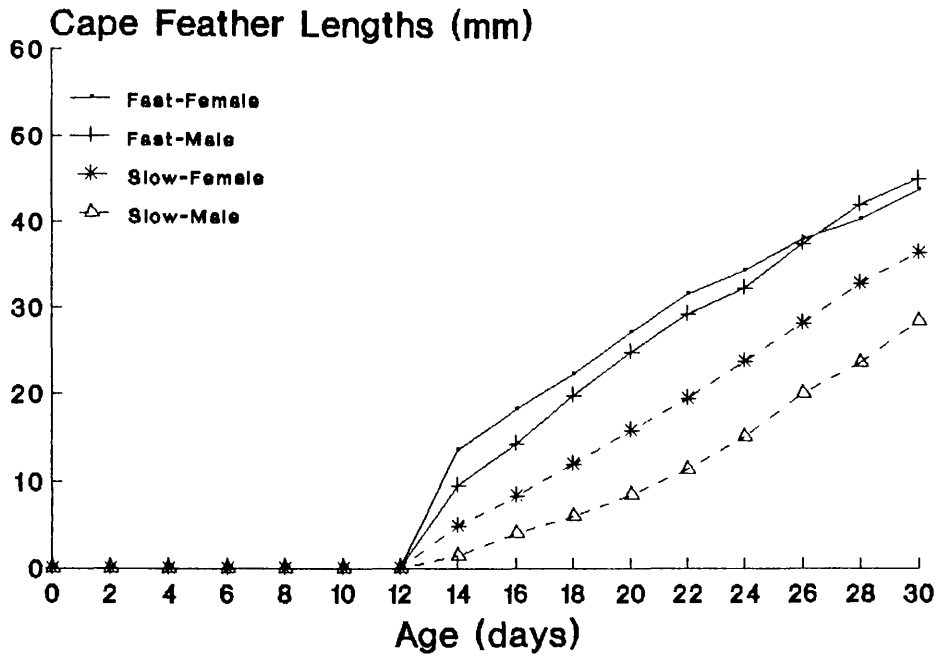


Figure 6.13. Effects of age, line and sex on cape feather lengths

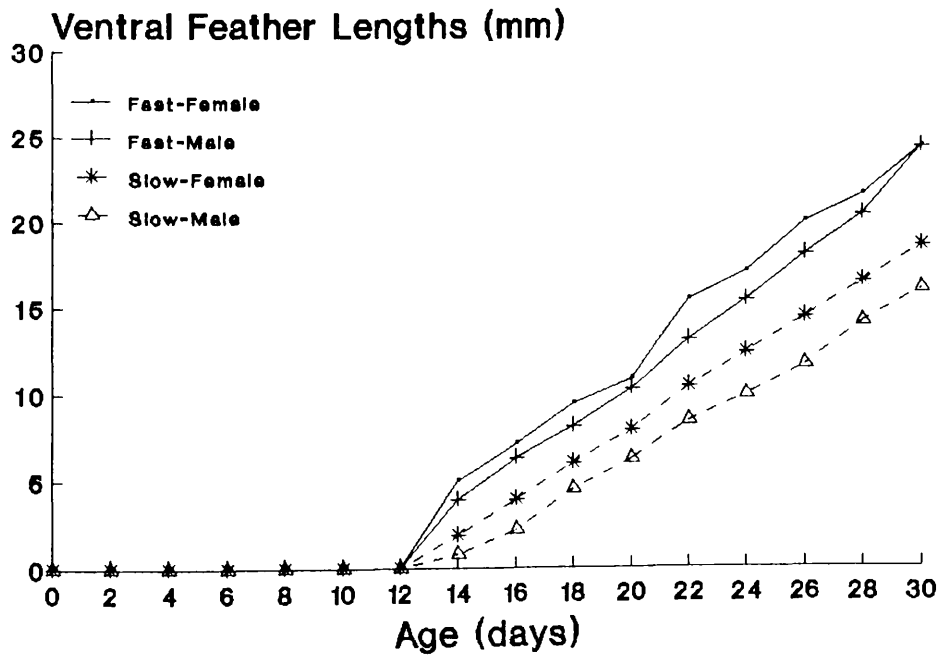


Figure 6.14. Effects of age, line and sex on ventral feather lengths

30 days of age.

The cape feather length gain was greater in the fast line than in the slow line from 12 to 22 days of age. After this age, the slow females were found to have longer feathers than the fast females. In general, the fast line had greater ventral feather length gain than the slow line from 12 to 30 days of age. The average of cape feather length gain was 3 and 2 mm/2 days and the ventral feather length gain was about 2 and 1 mm/2 days in the fast and slow feathering lines, respectively.

VI.3.7. Body Weight

The mean body weight of the fast feathering line was greater than that of the slow line at hatching and at ten days of age. Body weight gain in the fast line was greater than these in the slow line from hatching to ten days of age (fast= 17.8 g/d; slow= 15.4 g/d). But there was no difference in body weight gain between the sexes.

At 20 days of age, the mean body weight of males was greater than that of females in each line. Also the mean body weight of fast females was no different from that of the slow males. The fast males grew faster than the others from 10 to 20 days of age. Furthermore, in the slow line, the males had more weight gain than the females.

At 30 days of age, the mean body weight in the fast line was greater than that in the slow line and males were heavier than females. The fast line was growing faster than

the slow line and body weight gain was greater in the males than in the females from 20 to 30 days of age (Figs. 6.15 and 6.16).

VI.3.8. Photography of Birds

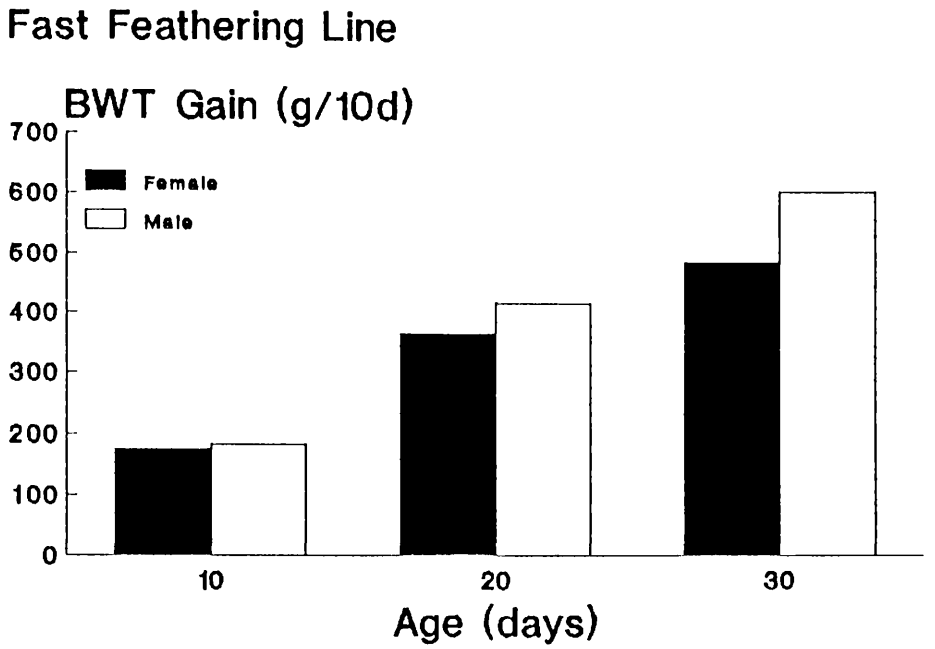
The photographs of the fast and slow feathering birds from each sex at 10, 20 and 30 days of age are presented in Plates 6.1-6.12. The series of photographs show that fast feathering line had better feathering than slow feathering line in the area of the back, thigh and breast up to 20 days of age. However, at 30 days of age, the feather cover of slow feathering females was almost the same as that in fast feathering females.

VI.4. DISCUSSION

The result of experiment represent the first comprehensive quantitative description of emergence of feathers in the various tract and the growth of the feathers up to 30 days of age. Therefore no other information with which to draw comparison.

Feathers do not cover the body of the bird uniformly, but grow in rows to produce tracts or areas over the body. The various stages of feather development is affected by genetics, sex and nutrition.

Figure 6.15. Effects of age, line and sex on body weight.



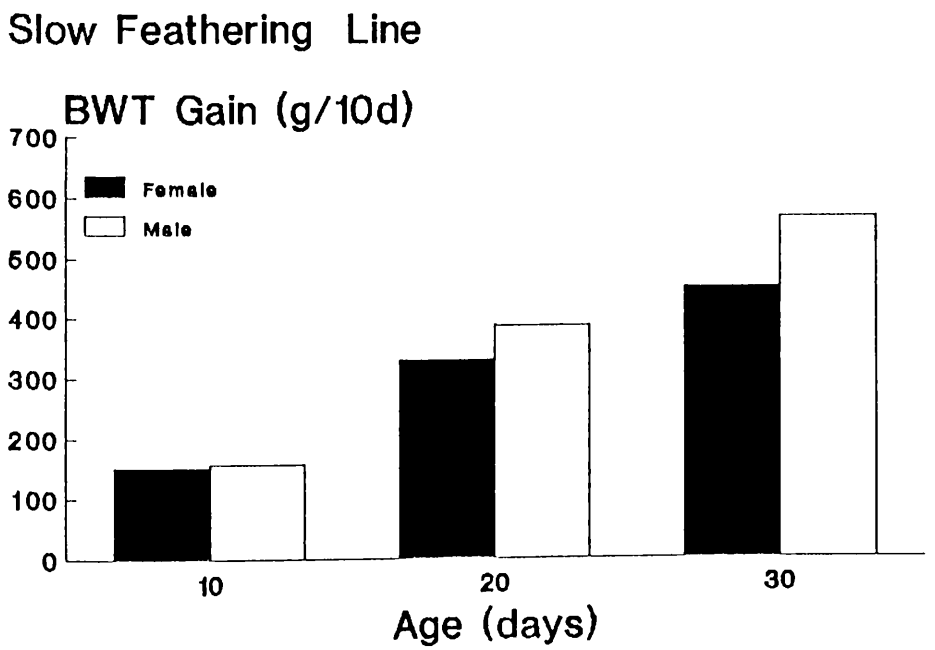


Figure 6.16. Effect of sex on body weight gain of fast and slow feathering lines

Plate 6.1. Photographs of the back and wing area of a fast feathering female at 10, 20 and 30 days of age

Fast
Female

10
Days

20
Days

30
Days

Plate 6.2. Photographs of the back and wing area of a fast feathering male at 10, 20 and 30 days of age

Fast Male

10 Days

20 Days

30 Days

Plate 6.3. Photographs of the back and wing area of a slow feathering female at 10, 20 and 30 days of age

Slow Female

10 Days

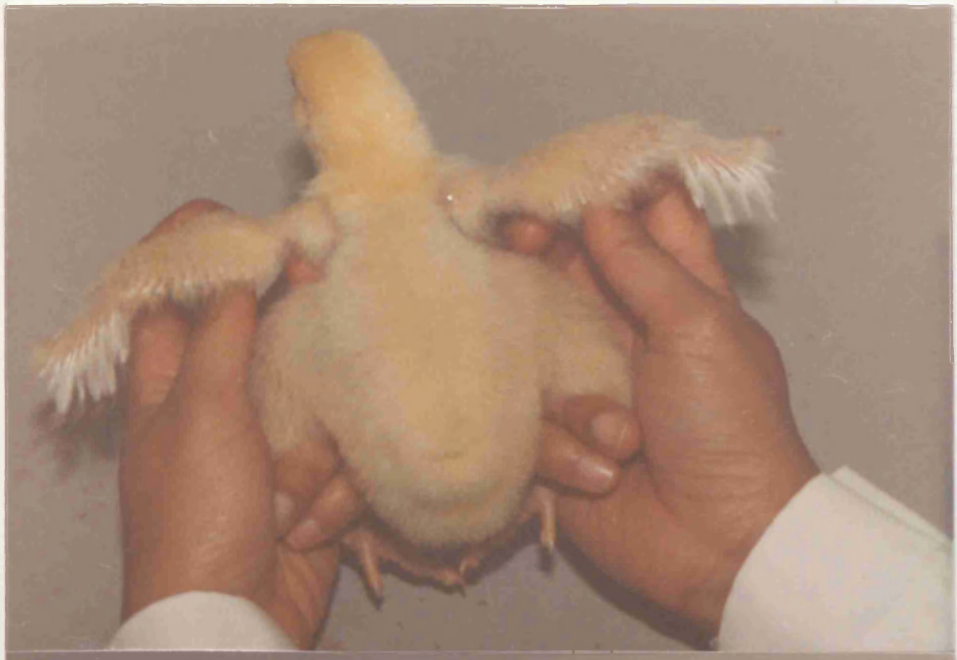
20 Days

30 Days

Plate 6.4. Photographs of the back and wing area of a slow feathering male at 10, 20 and 30 days of age

Slow Male

10 Days



20 Days

30 Days

Plate 6.5. Photographs of the side of the body of a fast feathering female at 10, 20 and 30 days of age

Fast
Female

10
Days

20
Days

30
Days

Plate 6.6. Photographs of the side of the body of a fast feathering male at 10, 20 and 30 days of age

Fast
Male

10
Days

20
Days

30
Days

Plate 6.7. Photographs of the side of the body of a slow feathering female at 10, 20 and 30 days of age

Slow
Female

10
Days

20
Days

30
Days

Plate 6.8. Photographs of the side of the body of a slow feathering male at 10, 20 and 30 days of age

Slow Male

10 Days

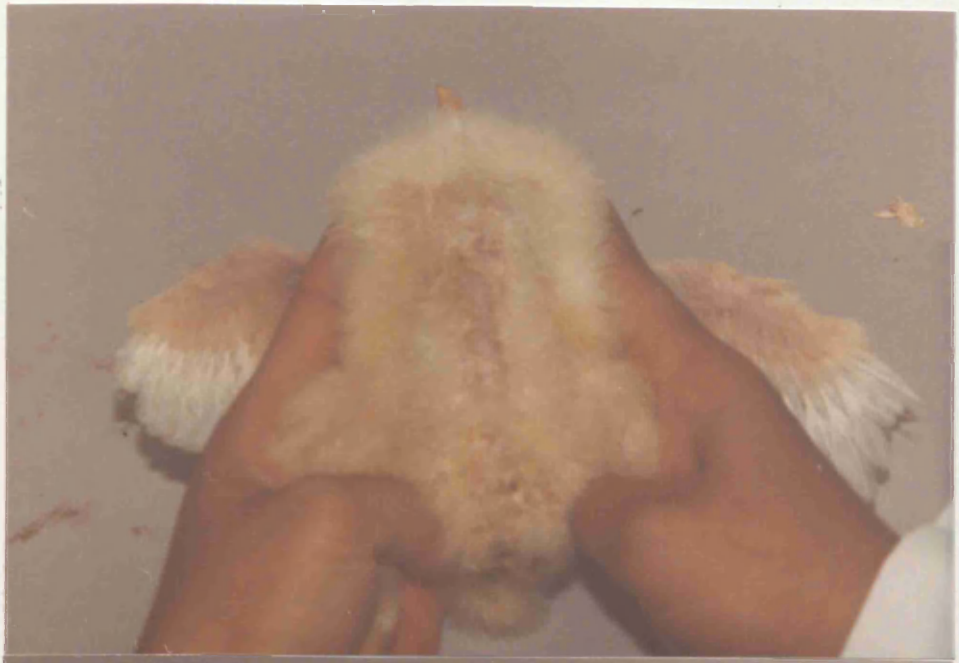
20 Days

30 Days

Plate 6.9. Photographs of the breast area of a fast feathering female at 10, 20 and 30 days of age

Fast
Female

10
Days



20
Days

30
Days

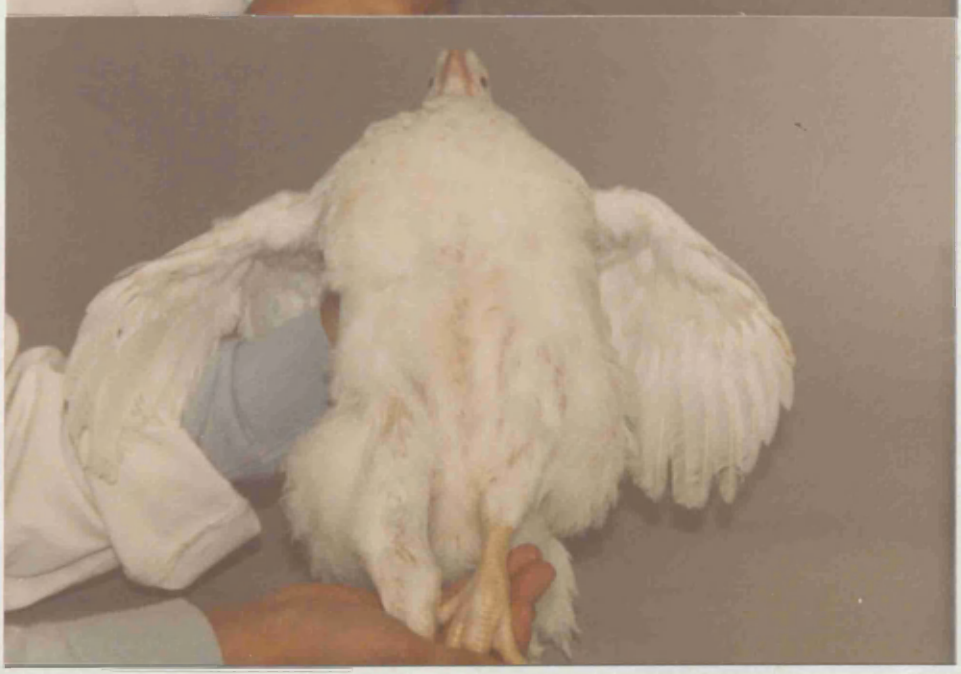


Plate 6.10. Photographs of the breast area of a fast feathering male at 10, 20 and 30 days of age

Fast
Male

10
Days

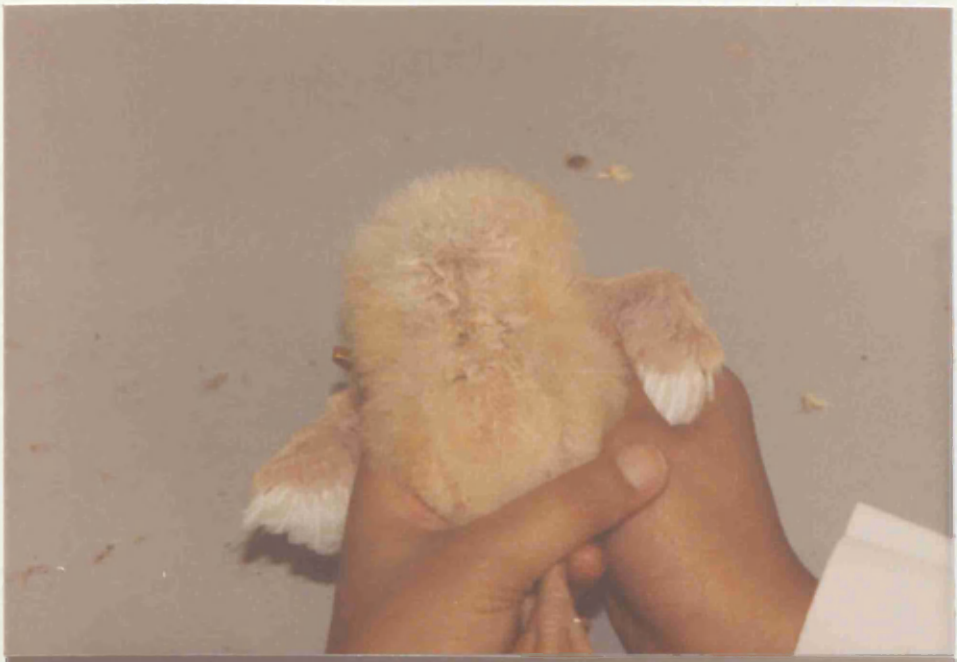
20
Days

30
Days

Plate 6.11. Photographs of the breast area of a slow feathering female at 10, 20 and 30 days of age

Slow
Female

10
Days



20
Days

30
Days

Plate 6.12. Photographs of the breast area of a slow feathering male at 10, 20 and 30 days of age

Slow Male

10 Days

20 Days

30 Days

The differences which exist in the rate of feathering are important to be observed at an early age, since when adult fast and slow feathering birds cannot be distinguished in feathering from each other. Therefore when selecting replacements, birds showing the undesireable feathering should be eliminated from the potential breeding flock at an age when the type of feathering is still readily identifiable.

In this study the observations on feather growth were carried out during the first 30 days of the birds' life. Appearance of the feather tracts and the number of the feathers emerged from their sheaths, feather lengths and body weight will be discussed. Furthermore, correlations between feather lengths at hatching with those in the later ages or feather lengths with body weight will also be discussed.

VI.4.1. The Appearance of the Feather Tracts and the Number of the Feathers Emerged from Their Sheaths

Feathers do not cover the body of the bird uniformly, but grow in rows to produce tracts; namely, the head, shoulder, wing coverts, hackles, cape, back, saddle, breast, ventral, thigh and leg (Lucas and Stettenheim, 1972). Fowls also possess primary and secondary wing feathers and main tail feathers. In this study, the observation of the appearance of the tracts was carried out in 8 of those tracts (except saddle and wing coverts). In addition to

these 8 tracts, the observation was also carried out on primary and secondary wing feathers and tail feathers. The recording of feathers emerged from their sheaths was carried out only in primary and secondary wing feathers, shoulder, cape, back, breast, and thigh feathers since the calculation of the number of feathers emerged in those tracts was easier than in the other tracts. The primary and secondary feathers appeared at hatching. This observation is supported by Warren (1925) who reported that in all breeds, the primary wing feathers are the first to appear.

The observation of the order of appearance in the eight tracts and tail feathers in this study showed that the shoulder and the tail feathers were the next feathers to appear after the primary and secondary flight feathers (at about 6 days of age). The order of appearance in the others varied between lines, and, between the sexes in the slow line. This observation is in close agreement with Warren (1925) who concluded that the tail feathers are usually the next feathers to appear after the primary and secondary flight feathers. Radi and Warren (1938) reported that usually the shoulder, thigh and breast were the first regions to show feather development. The variation in the order of appearance of the tracts was mainly due to the different strains they used.

The appearance of tail feathers at about 10 days of age and cape feathers at about 14 days of age in slow males was very late compared with that in the fast line and in slow females. The appearance of thigh, ventral and head feathers

in slow females was slower than in the fast line. Only the tail feathers showed a difference between males and females in the slow line since a higher percentage of slow females were seen to have tail feathers about four days earlier than slow males. Radi and Warren (1938) found that tail feathers are likely to appear earlier in females than in males. Furthermore, Hays and Sanborn (1942) reported that tail feathers started about three days earlier in females than in males.

The observation of primary and secondary feathers emerged from their sheaths showed that at an early age (between 2 and 6 days), the fast line had more feathers emerged than the slow line, and females had more of these feathers than males. In the females breast, tail, shoulder and cape feathers emerged from their sheaths about two days earlier and in greater numbers than males. The fast line showed a superiority in feathering over the slow line as the fast line had more feathers emerged from their sheaths and at earlier stage. This result is in agreement with Radi and Warren (1938) who concluded that feathering is greatly affected by sex, since the time of appearance of feathers and their rate of growth seem to be closely associated with sex. Gericke and Platt (1932) reported that the time of feathers appearance in the tracts varied greatly in individual birds. The individual differences might have been due to varying protein intake caused by the birds consuming different quantities of food, but this could not be checked, as the birds were fed as a flock. The difference between

birds would also be due to genotype variation within a line/sex.

In general, this study shows that by 30 days of age, the chick was fully feathered. This result is in agreement with North (1984) who concluded that by the time a chick is 4 or 5 weeks of age (about 28 to 35 days of age) it is fully feathered. Also Deschutter and Leeson (1986) reported that the period of maximum feather growth differs between males and females.

VI.4.2. Feather Lengths

In this study the measurement of feather lengths was carried out only in primary, secondary, tail, cape, back, breast and ventral (sternal) feathers. At hatching, the primary and secondary feather lengths in the fast line were longer than in the slow line. In the fast line, females had longer primary feathers than males, but in the slow line, the difference in this feather length between females and males was not significantly different. At hatching, there was no difference in secondary feather lengths between these sexes in both lines.

Fast females had longer primary and secondary feathers than fast males up to 12 days and 24 days of age respectively. But, after 22 days of age for primary feathers and 28 days of age for secondary feathers, the fast males had longer feathers than those of the fast females. The slow females showed a superiority over slow males in primary

and secondary feather lengths up to 30 days of age. In general, the primary and secondary feather lengths were found to be longer in the fast line than in the slow line from hatching to 30 days of age.

The ratio of secondary to primary feather lengths is shown in Fig. 6.17. In the slow line, this ratio could be used to distinguish between males and females from hatching to 10 days of age, since this ratio was higher in females than in males, especially at about 4 to 8 days of age. Although in fast females there was a higher ratio of secondary to primary feather lengths than in fast males at hatching day, the difference was not very great.

The effect of genotypic selection in the other feathers could be distinguished clearly from about 8 days of age. At this age, the tail feather lengths of fast and slow lines and those in females and males in both lines could be distinguished clearly, since the fast line had longer tail feathers than the slow line and females had longer feathers than males. This distinction became obvious in breast and back feather lengths at about 10 days of age and in cape and ventral feathers at about 14 days of age.

At 6 days of age, tail feathers could be used to distinguish between fast and slow lines. At this age, the tail feathers in the slow line had not yet appeared. In this study, generally, the difference in tail feather length between the fast and slow lines and between sexes in each line became obvious from 8 to 30 days of age. Hays (1952) suggested that the endocrine system operates to regulate

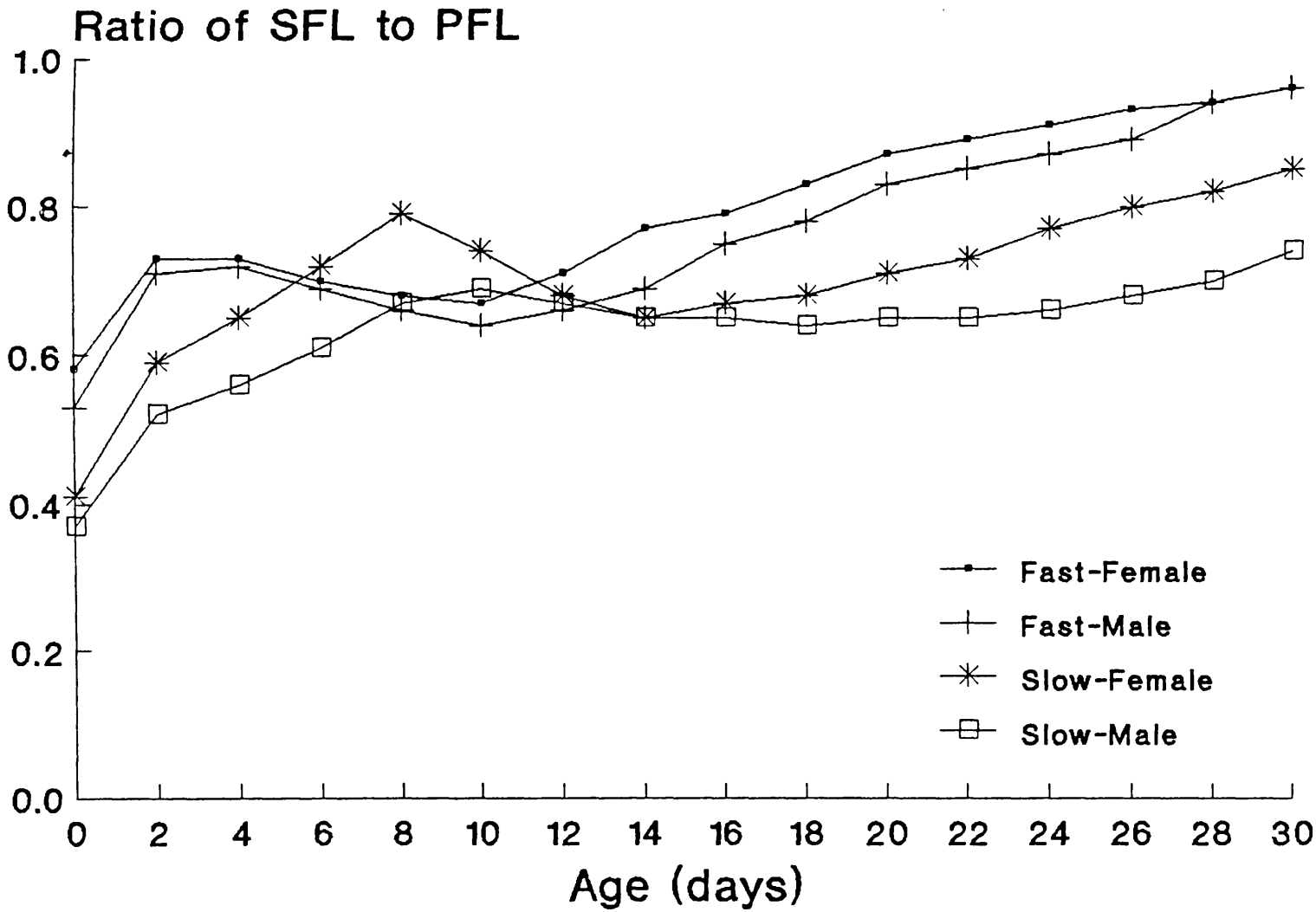


Figure 6.17. Effects of age, line and sex on the ratio of secondary feather length to primary feather length

tail length resulting in a sex difference that is significant.

It was found that back feathers appeared at about 10 days of age, except for slow males as they still did not have feathers yet in the back tract. The difference in back feather length between the two lines and also between the sexes in both lines could be seen clearly from 10 to 24 days of age. From 24 days of age, in the fast line, no difference in back feather length between males and females was found. In the slow line, females still had longer back feathers than males up to 30 days of age. Siegel *et al.* (1957a) showed that females were superior to males on the basis of back scores at 10 days of age, and McDougald and Keshavarz (1984) reported that back feather scores were similar in male and female chicks at 52 days of age.

In general, this study showed that the fast line had better feathering than the slow line and females had better feathering than males. It seems that the fast feathering genes speed up feather production in all tracts examined and sex is an important factor influencing the rate of feathering. Several workers reported that females had better feathering than males due to the production of thyroxine and estrogen which is greater in females than in males during the first weeks of life (Radi and Warren, 1938; Schultze and Turner, 1945; Glazener and Jull, 1946; Sturkie, 1954; Siegel *et al.*, 1957a).

VI.4.3. Body Weight

At hatching, the average of body weight of fast females (43.6 g) was 2.4 g more than that of slow females. The average body weight of fast males (44.4 g) was 3.1 g greater than that of slow males. However, the average body weight of males and females in each line at hatching and 10 days of age were not significantly different. Evidence is presented in Chapter VII to suggest that egg weight differences between lines are a likely cause of the chick weight differences. According to Morris *et al.* (1968), a strong positive relationship was found between the weight of the chick at 1 day of age and egg weight for both males and females, the hatching weight being 66.8 per cent and 66.4 per cent of the egg weight on average, respectively. They reported that no significant difference overall in body weight at 1 day of age between the two sexes.

At 20 and 30 days of age, the males of both lines were found to be growing significantly faster than the females and the difference between the two sexes increased with increasing age. Lowe and Merkley (1986) reported that gain and body weight were greater in males than females.

At 30 days of age, in the fast line, the mean body weight of males was 179.5 g more than that of females. In the slow line, the mean body weight of males was 181.4 g more than that of females. Thus the sexual dimorphism in similar between lines. For females, the mean body weight in the fast line was 98.6 g more than in the slow line. For males, the mean body weight in the fast line was 96.7 g more

than in the slow line. In this experiment the slow feathering gave an equal disadvantage to both sexes. This supports the early work of Hutt (1949) who reported that rapid feathering birds having better insulation against heat loss, require less energy for the maintenance of body temperature and thus more energy is then available for growth.

VI.4.4. Correlation Between the Traits

In the primary and secondary feathers there were correlations between feather length at hatching and at 30 days of age of r=0.38 and r=0.48, respectively. The tail, back and breast feathers there had strong correlations between feather lengths at 10 days and 30 days of age. In the case of ventral and cape feathers there were strong correlations between feather lengths at 20 and 30 days of age.

In general, primary and secondary feather lengths at hatching had a strong positive correlation with, secondary, tail, back, breast, ventral, and cape feather lengths at 30 days of age, whereas, the tail, back and breast feather lengths at 10 days of age and the cape and ventral feather lengths at 20 days of age had a correlation with better feathering at 30 days of age (Table 6.2). This result is supported by Glazener and Jull (1946) who concluded that the degree of feathering at hatching time was related to the degree of feathering at 10 days and at 8 weeks of age.

Table 6.2. Correlation (r) between feather length at different age and feather length at 30 days of age

Days	Feathers	30 Days of Age						
		Primary	Secondary	Tail	Back	Breast	Ventral	Cape
0	Primary	**0.38**	0.59	0.65	0.62	0.57	0.67	0.61
	Secondary	0.48	**0.61**	0.74	0.61	0.51	0.67	0.63
10	Primary	**0.56**	0.83	0.87	0.80	0.68	0.85	0.80
	Secondary	0.60	**0.79**	0.83	0.73	0.71	0.77	0.79
	Tail	0.32	0.62	**0.92**	0.77	0.61	0.80	0.70
	Back	0.19	0.50	0.74	**0.60**	0.46	0.66	0.56
	Breast	0.34	0.68	0.86	0.81	**0.66**	0.82	0.73
20	Primary	**0.84**	0.92	0.73	0.73	0.78	0.73	0.87
	Secondary	0.66	**0.92**	0.88	0.87	0.78	0.88	0.89
	Tail	0.37	0.70	**0.96**	0.79	0.66	0.83	0.73
	Back	0.54	0.81	0.87	**0.87**	0.71	0.88	0.84
	Breast	0.53	0.82	0.89	0.89	**0.79**	0.91	0.89
	Ventral	0.47	0.75	0.78	0.82	0.73	**0.84**	0.79
	Cape	0.57	0.87	0.89	0.91	0.81	0.93	**0.92**

Table 6.3. Correlation (r) between feather length and body weight at the same age

Feathers	0	10	20	30
	Days			
Primary	0.26	0.51	0.19	0.06
Secondary	0.25	0.39	0.26	0.11
Tail	-	0.52	0.22	0.02
Back	-	0.42	0.28	0.15
Breast	-	0.53	0.31	0.06
Ventral	-	-	0.31	0.22
Cape	-	-	0.26	0.14

Darrow and Warren (1944) showed that the degree of development of ten-day tail feathers was highly correlated with broiler feathering.

Body weight and secondary feather lengths at hatching time had low correlations with 30-day body weight, r=0.27 and r=0.03 respectively. The primary feather lengths at hatching did not have a correlation with 30-day body weight. In general, there were low correlations between feather lengths and body weights at hatching, 10, 20 and 30 days of age. However, the highest correlation was found between feather length and body weight at 10 days of age (Table 6.3). Goodman and Muir (1965) concluded that the birds which were better feathered usually had a slightly larger body weight. The relationship between feathering and body weight seemed to be at a maximum during the first few weeks after hatching. This degree of relationship is not surprising since during the early weeks of life when body growth rate is heading towards the asymptote, at around 8 weeks of age in broilers, feather growth has accelerated to an asymptote at about 4 weeks of age.

CHAPTER VII. EXPERIMENT 4:
THE PERFORMANCE OF BROILER BREEDERS

VII.1. INTRODUCTION

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.

In this study, the divergent selection for the fourth generation was carried out from two hatches. Edriss (1988) had taken the selection process to the third generation. At 25 days of age, predicted tail length from the multiple regression equation was employed to be the criterion for selection of fast feathering birds within the fast line and slow feathering ones among the slow line. Selections were made without regard to parental origin although number retained from each hatch reflected the relative numbers of chicks in the two hatches.

This experiment was conducted to obtain an information in the performance of the fourth generation of fast and slow feathering lines of broiler chickens such as feather growth, body growth, egg production and egg composition.

VII.2. MATERIALS AND METHODS

VII.2.1. Experimental Design

This experiment followed a 2 x 3 x 2 factorial design for analysis of the effect of hatch at hatching day, and the three factors were two hatches, three lines and two sexes. Then followed a 2 x 3 factorial design for the analysis of feathers, body growth and egg composition, with two ages and three lines. Finally a 10 x 3 factorial design was used for the analysis egg production, with ten ages and three lines.

VII.2.2. Birds and Management

In each line, a total of eight potential third generation males were used as the sire of the fourth generation. In the fast and control lines, six females were assigned to mate with one male. Due to a small number of females of slow line, four females were assigned to mate with one male.

A mating was carried out by artificially inseminating each hen with semen from a specific sire. The artificial insemination was carried out twice a week. If the semen production of a sire was not enough to cover all the females which they were assigned to, therefore the priority of the second artificial insemination was for those which did not get any semen at the first insemination.

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

The eggs from each hen were collected daily on the basis of their line, and the cage number was marked on the shell. Approximately 360 eggs were collected to produce about 180 chicks in each line.

In this study, two hatches were taken off. At hatching day, the chicks were wing banded according to sires and dams, then they were vent-sexed. The chicks from the first hatch were housed on 2nd March 1989 and the chicks from the second hatch were housed on 9th March 1989.

VII.2.3. Selection Procedure

In the fourth generation, a total of 25 males and 75 females were randomly selected from the control line progeny at 25 days of age. The criterion for selection of fast feathering birds within the fast line and slow feathering birds among the slow line was based on predicted tail length from the following regression equation:

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

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;

Predicted tail lengths were estimated for males and females within each line.

In order to minimise the 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.

When the fourth generation flock was 30 weeks old, the first artificial insemination was carried out to produce some broiler chicks for another experiment (Chapters VIII, IX and X).

VII.2.4. Housing

The experiment was conducted in three pens. One pen had dimensions 540 x 780 cm for 350 chicks from the first hatch, while two other pens had dimensions 320 x 320 cm for 115 females and 122 males of the chicks from the second hatch. After 16 weeks of age, the birds were separated into 9 pens in which all females and males were separated. The layout of the pens are shown in Fig. 7.1. The space for

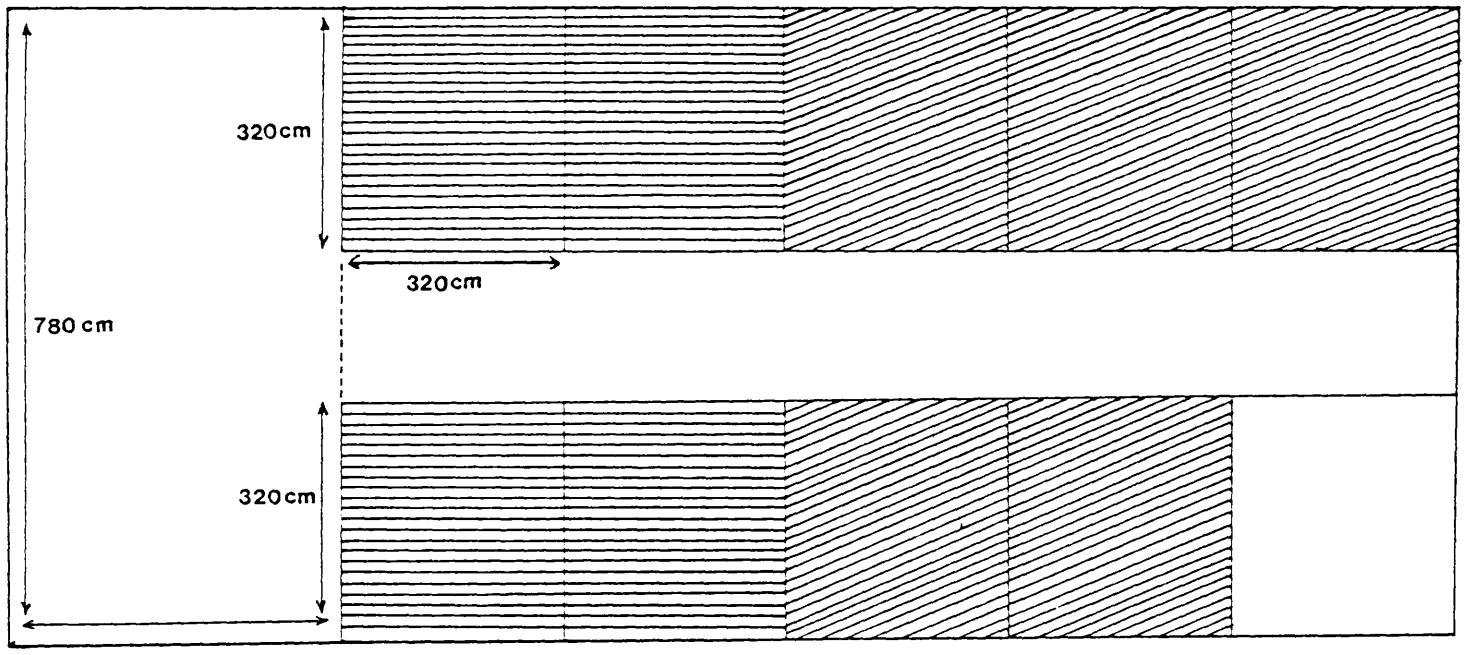


Figure 7.1. The final layout of the pens in rearing house.
▤ = Males, ▨ = Females

females was 6 birds/m^2 and for males was 4 birds/m^2. When the females reached 22 weeks old, they were moved into individual cages. The cocks were moved into individual cages after they were 24 weeks of age. The layout of the hens' and cockerels' house is shown in Fig. 7.2.

In the rearing house, heat was supplied by gas brooders and brooding temperature was about 32^{o}C decreasing steadily to 21^{o}C at 21 days of age. Thereafter it was maintained at 21^{o}C until 22 weeks of age. The temperature in the hens' and cockerels' house was maintained at 21^{o}C. The lighting programme was 23 hours light and one hour dark up to 24 days of age. Then, it was sharply reduced within a week to eight hours light which was held constant up to 22 weeks of age.

The lighting in the hens' and cockerels' house had to be set to supply 11 hours of light per day (11L:13D) during 23 and 24 weeks of age, then increasing one hour every two weeks up to 16 hours of light per day (16L:8D) by 33 weeks of age. Thereafter, the day length was kept at 16 hours of light (16L:8D) until the end of this experiment.

VII.2.5. Diets

For the first 25 days the birds were given a commercial broiler starter diet *ad libitum* (up to the measurements for selection). Thereafter, up to six weeks of age the birds were fed the same diet but in restricted form.

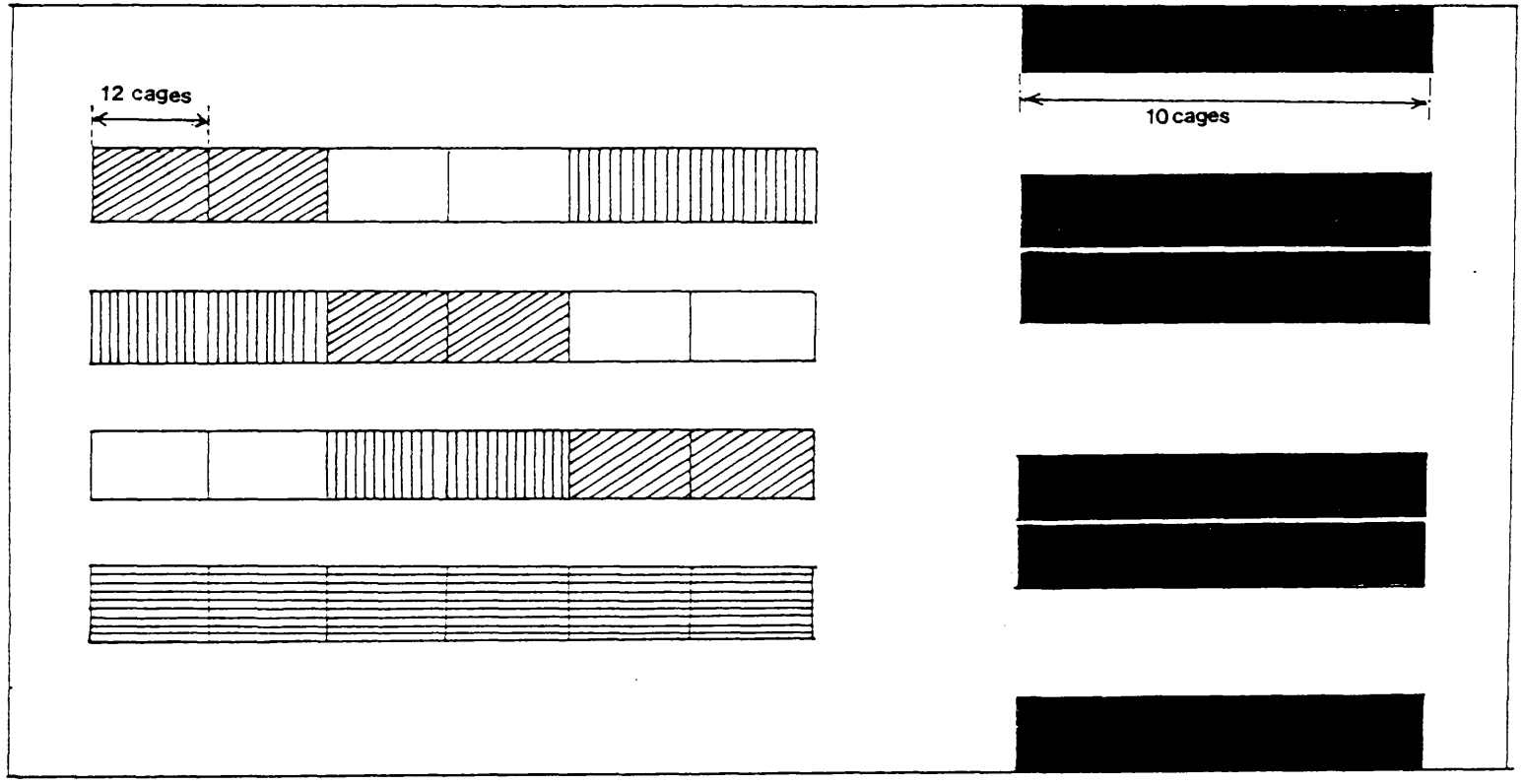


Figure 7.2. The layout of the cages in the hens'/cockerels' house. ▨ =Fast Females, □ = Control Females, ▨ = Slow Females; ▤ = Spare Females; ■ = Males; 1 cage= 1 bird

From 7 to 22 weeks of age, the birds were fed a pelleted commercial grower diet in restricted form. Except during 8 to 10 weeks of age, food was permitted *ad libitum* since they had a health problem.

At the beginning of the pre-production period, hens were switched from the grower ration to a commercial breeder ration in mash form, while the males continued to get the grower ration. Both sexes were fed in a restricted way according to a feeding schedule (Appendix 12).

VII.2.6. Recording Procedures

a. Body Weight and Feather Lengths

Every two weeks, feathering measurements and body weight were recorded until 14 weeks of age. Feather length measurement were carried out for:

- primary and secondary wing feathers
- tail feather
- back feather

The methods for measuring those feathers can be seen in Chapter III.

b. Egg Production

The eggs were collected on the basis of their line and individually weighed every day from the first egg (25 weeks of age) until 10 weeks of egg production (34 weeks of age); after which egg collection continued from 40 to 49 weeks of

age. Egg production of per cent hen-day was calculated as:

$$\% \text{ Hen-Day Production} = \frac{\text{Number of eggs produced}}{\text{Number live hens}} \times 100\%$$

c. Egg Composition and Egg Mass

At 44 and 49 weeks of ages, the eggs were collected on the basis of their line and individually weighed. The egg was broken into a petri dish, the albumen was separated from the yolk with water vaccum pump and weighed. The shell was dried at the room temperature for 24 hours and weighed.

The following formula was used to compute egg mass on a daily basis.

$$M = P \times W$$

where: M = Egg mass (gram/day)

P = % hen-day production

W = Average egg weight (gram)

VII.3. RESULTS

VII.3.1. Hatch effect

At hatching day, there was no effect of hatch on primary and secondary feather lengths. Generally, the chicks from the second hatch had greater body weights than the first hatch (Table 7.1.).

Table 7.1. Effects of hatch, line and sex on body weight and primary and secondary feather lengths at hatching day

Hatch	Line	Sex	Body Weight (gram)	Primary Feather Length (mm)	Secondary Feather Length (mm)
1	Fast	M	48.3	11.3	7.5
		F	46.9	11.9	7.9
	Control	M	46.8	10.6	5.8
		F	47.5	10.7	6.4
	Slow	M	44.1	10.0	4.3
		F	42.6	10.2	4.8
2	Fast	M	47.7	11.0	7.5
		F	48.4	12.5	8.3
	Control	M	49.2	10.2	6.2
		F	48.6	10.8	6.8
	Slow	M	44.1	8.9	4.1
		F	43.5	9.7	4.9
SED			0.48	0.21	0.38
MAIN EFFECTS					
Hatch -	1		46.2	10.9	6.3
	2		47.0	10.7	6.5
SED			0.28	0.12	0.14
Line -	Fast		47.8	11.6	7.8
	Control		47.8	10.6	6.3
	Slow		43.5	9.8	4.5
SED			0.33	0.15	0.17
Sex -	Male		46.8	10.4	6.1
	Female		46.3	11.1	6.7
SED			0.28	0.12	0.14
Significance of Differences:					
Hatch (H)			**	NS	NS
Line (L)			***	***	***
Sex (S)			NS	***	***
H x L			NS	*	NS
H x S			NS	**	NS
L x S			NS	*	NS
H x L x S			*	NS	NS

M = Male; F = Female
NS = Non Significant; * = $P < 0.05$; ** = $P < 0.01$; *** = $P < 0.001$

The fast feathering chicks from both hatches had longer primary and secondary feathers and heavier body weights than those in the slow feathering line (Fig. 7.3).

VII.3.2. Body Weight

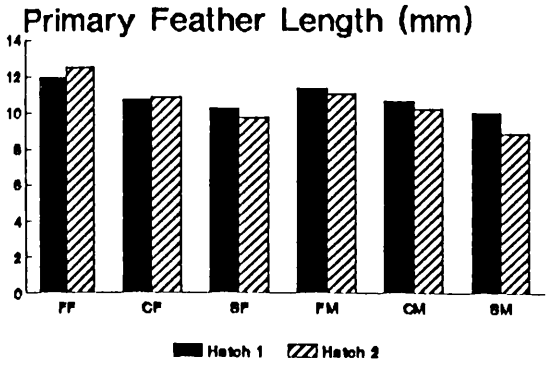
The birds were on *ad libitum* feeding until 25 days of age and again during 8 to 10 weeks of age when medication was taking place. During the remainder of the recording period the males and females were given regulated feeding and consequently by 14 weeks of age, the line difference were small.

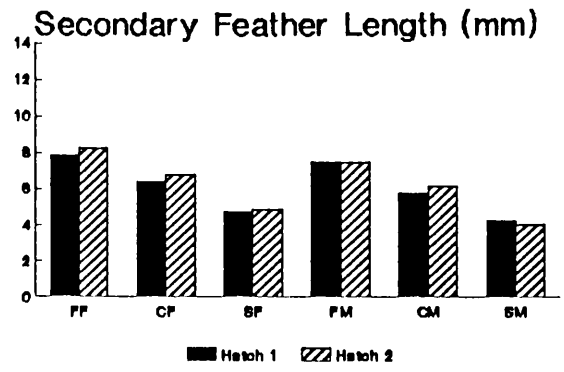
The effects of age and line on body weight can be seen in Fig. 7.4. Fast line birds had greater body weight than slow line birds in both sexes up to 14 weeks of age. At this age, the difference of body weight between fast females and slow females was very small.

The body weights of fast and slow hens at 32 and 49 weeks was not significantly different. However, the hens at 49 weeks of age (Fast= 3.8 kg; Slow= 3.7 kg) were heavier than these at 32 weeks of age (Fast= 3.6 kg; Slow= 3.6 kg).

VII.3.3. Feather Lengths

The effect of age, line and sex on feather lengths are presented in Figs. 7.5, 7.6, 7.7, 7.8 and 7.9.





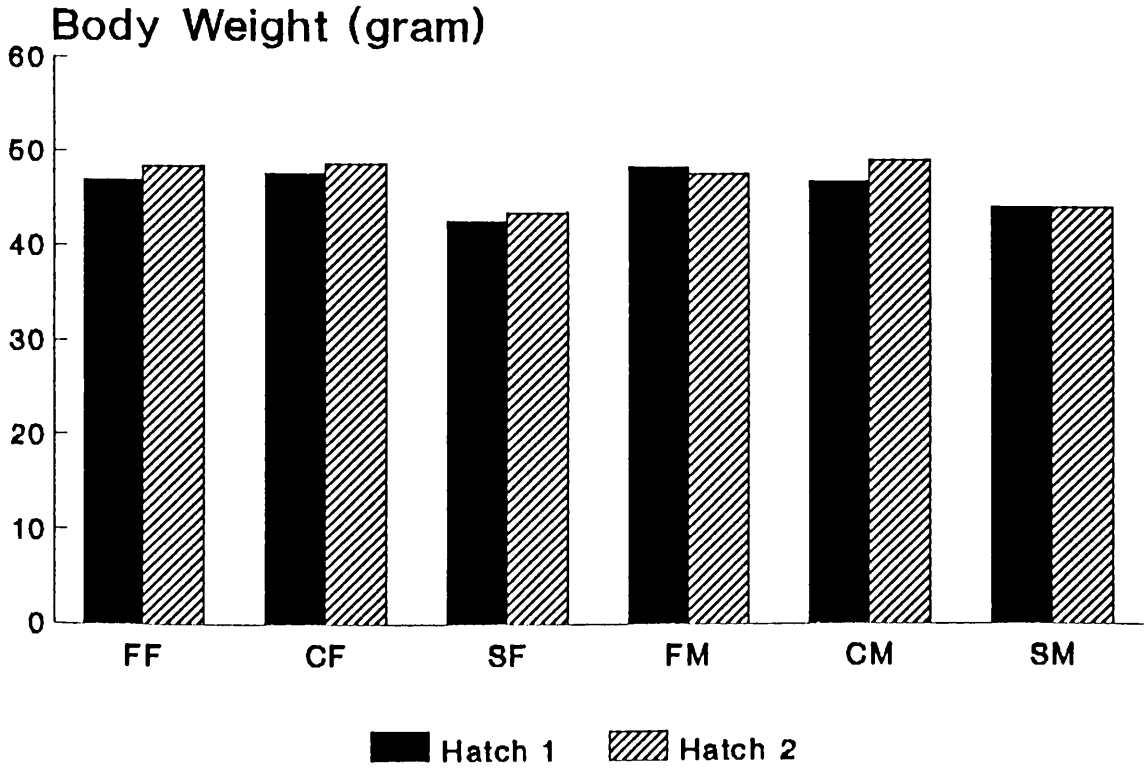
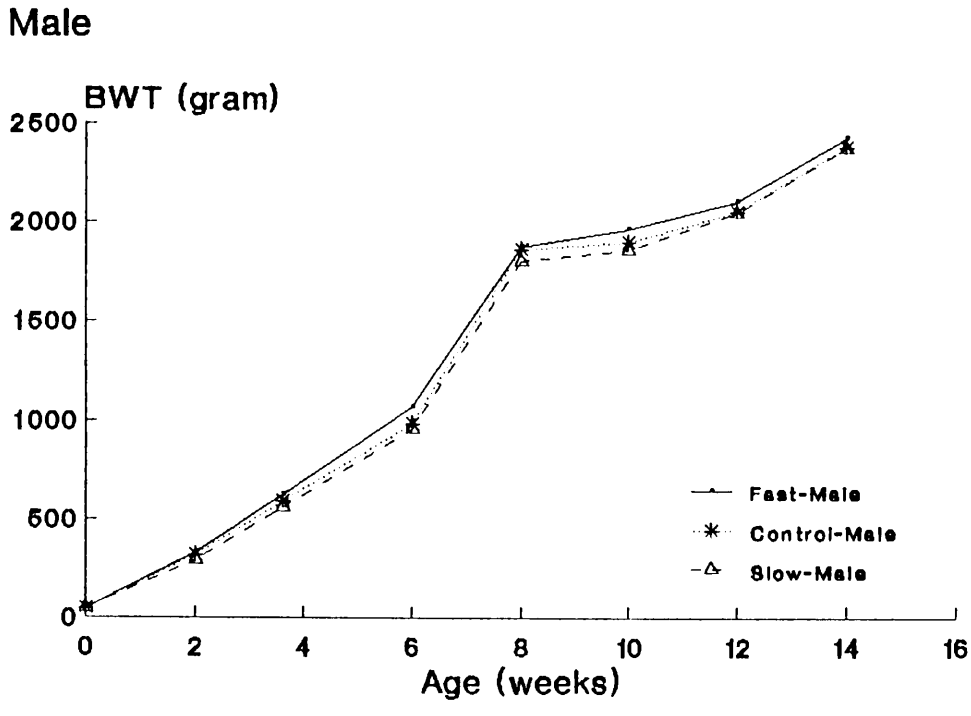


Figure 7.3. Effects of hatch, line and sex on body weight and lengths of primary and secondary feathers at hatching day (4th generation).
FF= Fast Female, CF= Control Female, SF= Slow Female,
FM= Fast Male, CM= Control Male, SM= Slow Male



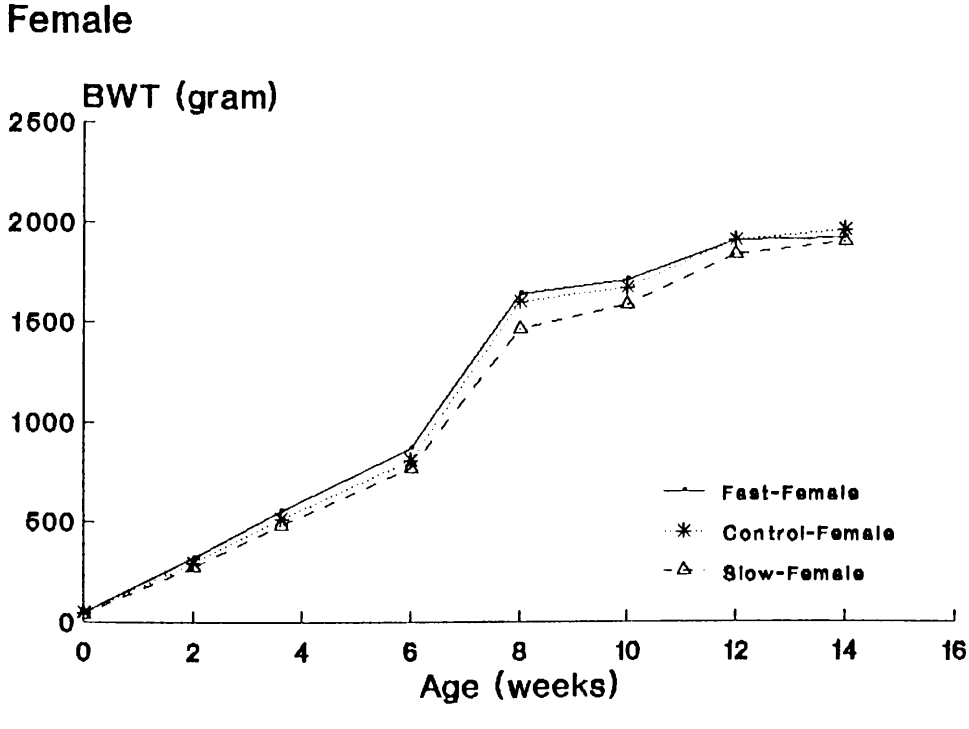


Figure 7.4. Effects of age and line on body weight (4th generation)

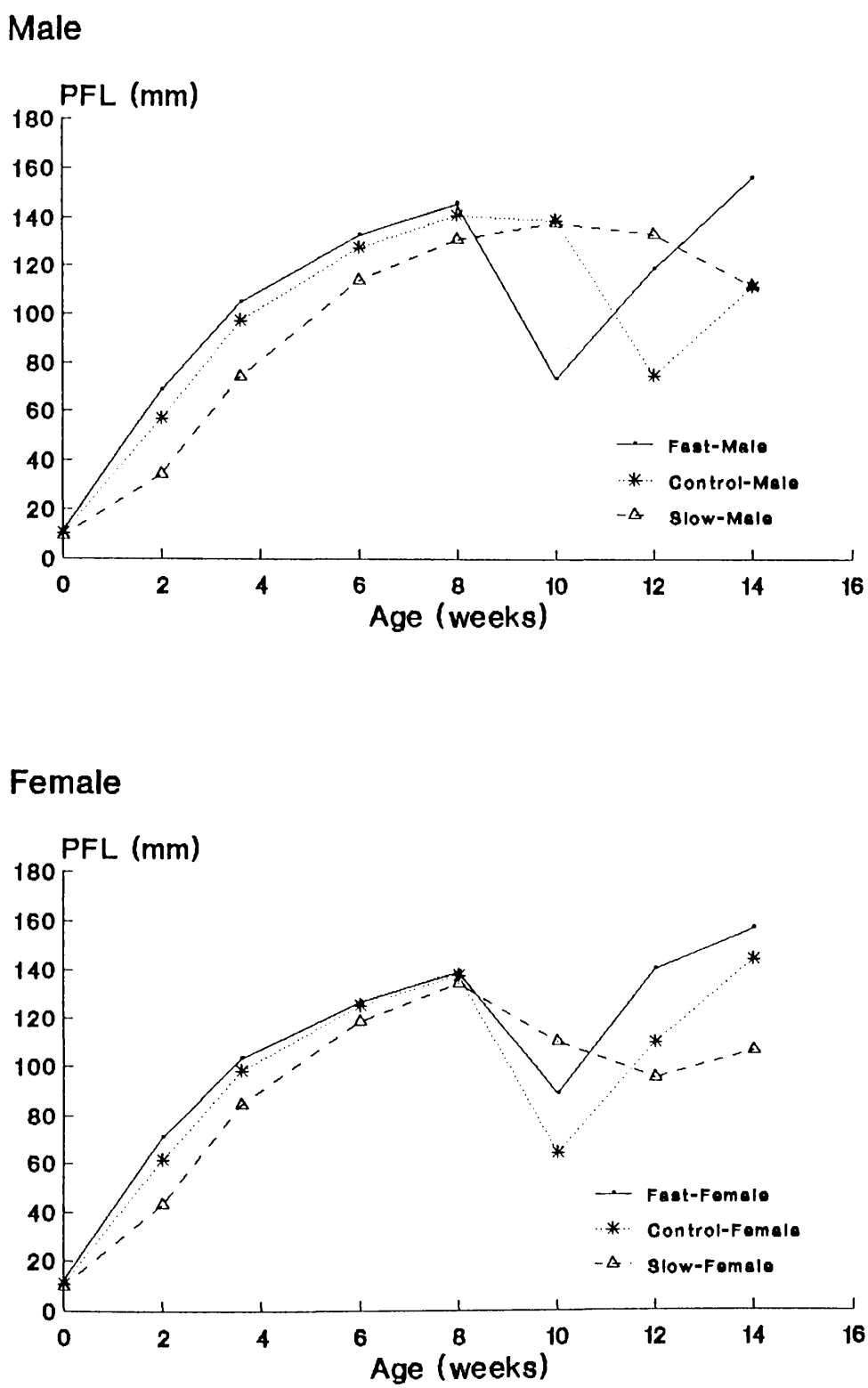


Figure 7.5. Effects of age and line on primary feather length (4th generation)

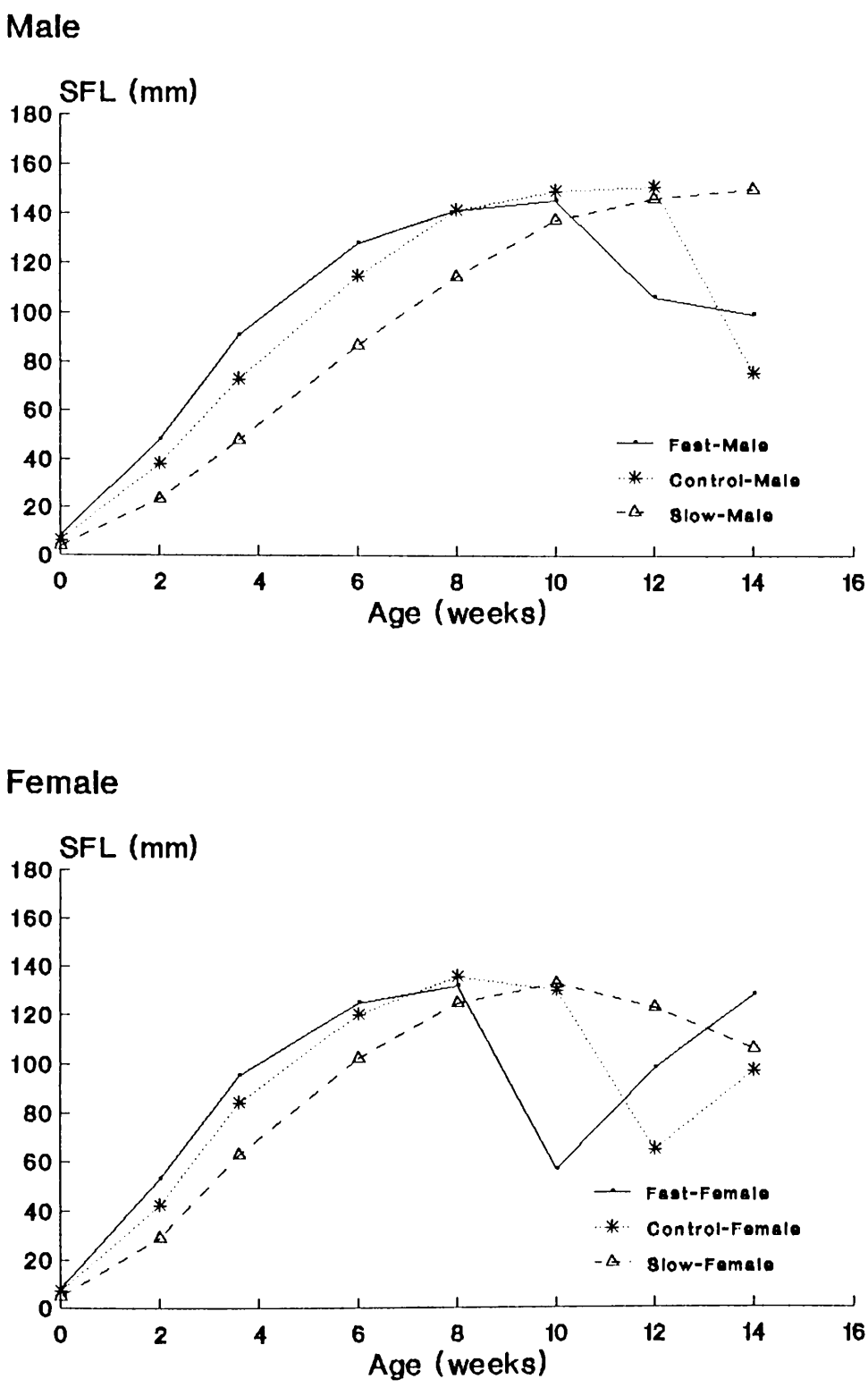


Figure 7.6. Effects of age and line on secondary feather length (4th generation)

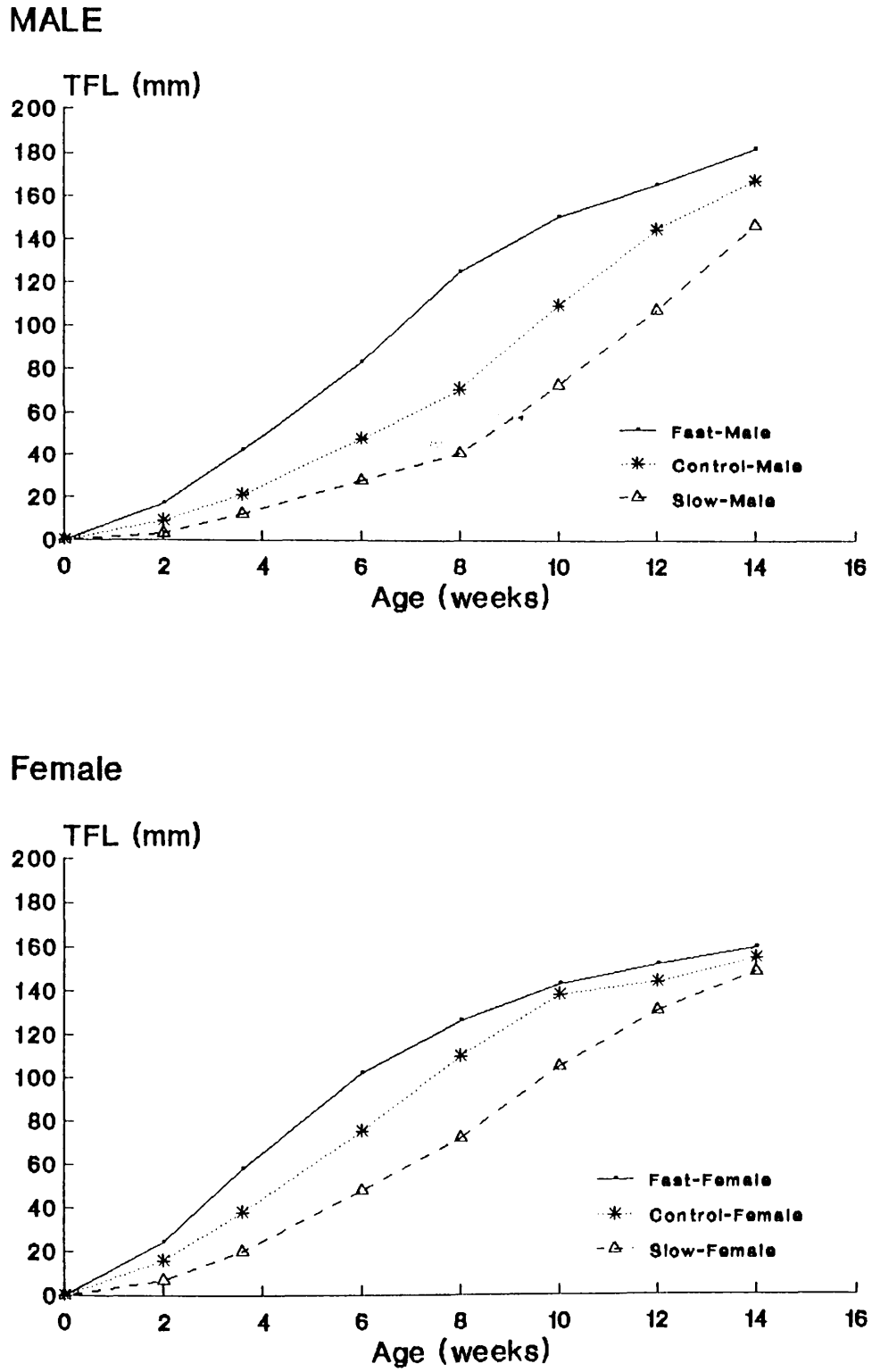


Figure 7.7. Effects of age and line on tail feather length (4th generation)

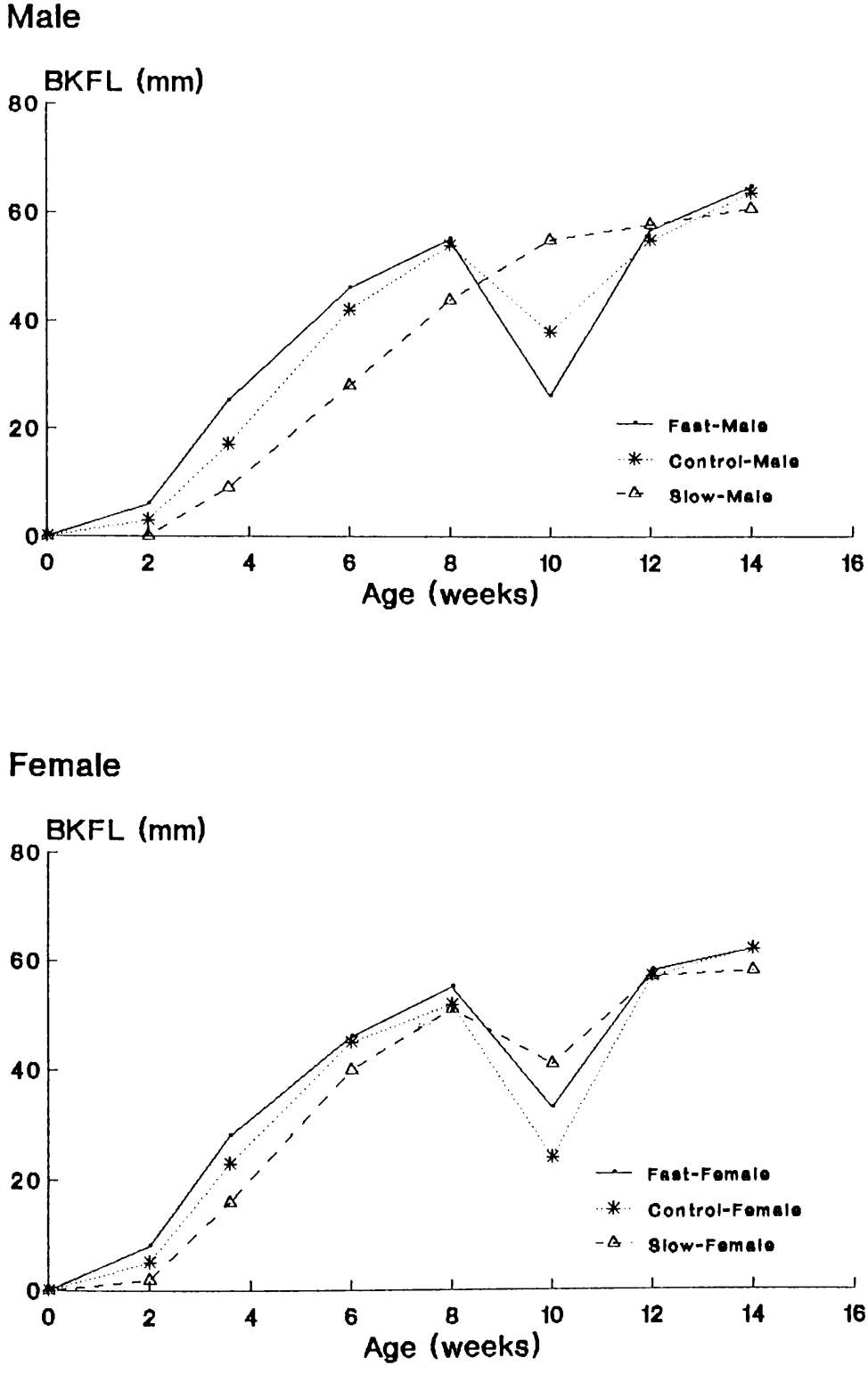


Figure 7.8. Effects of age and line on back feather length (4th generation)

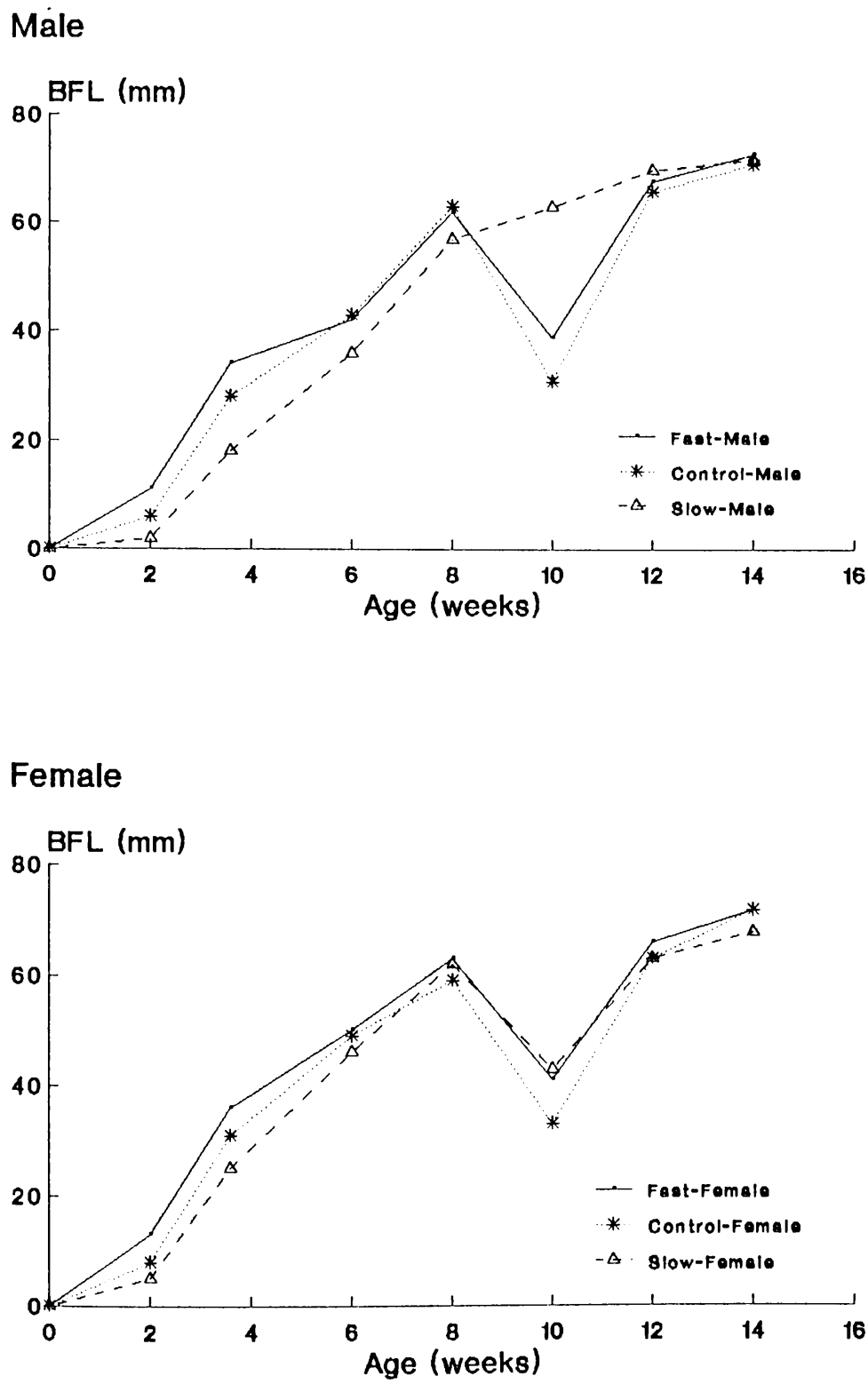


Figure 7.9. Effects of age and line on breast feather length (4th generation)

The fast feathering line had longer primary, secondary, breast and back feathers than the slow feathering line up to 8 weeks of age. But, the tail feathers in the fast feathering line were longer up to 14 weeks of age.

At 10 weeks of age, the fast feathering line had moulted the number 2 primary and secondary wing feathers and back and breast feathers. Only a slight evidence of moult was noted in slow feathering line; it seems that some of them continued to grow their feathers but at a slow rate. However, at 14 weeks of age, the fast feathering line had feathers longer than their feathers before moulting and also had longer feathers than the slow feathering line.

Females of fast feathering line had 3 mm longer primary and secondary feathers at 2 and 4 weeks of age respectively than in the males. But at 6 weeks of age, males had 7 mm longer primary and 4 mm longer secondary feathers than the females. At 6 weeks of age, the fast feathering females had 16 mm longer tail feathers than in the males, and at 14 weeks of age the fast feathering males had 23 mm longer tail feathers. In the slow feathering line, females had longer tail feathers than males up to 14 weeks of age, but the greatest difference of 33 mm was found at 10 weeks of age. The difference between males and females in breast and back feather lengths and back score were not different in fast, control and slow lines. However, females in the slow line seem to have moulted breast and back feathers at 10 weeks of age, but no moult of these feathers evident in the males of the same age even up to 14 weeks of age.

VII.3.4. Egg Production

The slow feathering line had a higher egg production (%HD) than the control or slow lines from the first week to tenth week of egg production (Fig. 7.10). But the slow line had smaller eggs than the control or fast lines (Fig. 7.11). However there was no significant difference in egg mass output (g/d) between those three lines (Table 7.2.)

The egg production recording was recommenced from 40 to 49 weeks of age. The slow line still had a higher rate of egg production than the fast or control lines.

VII.3.5. Egg Composition

The egg composition data was recorded at 44 and 49 weeks of age. The fast feathering line had a greater whole egg, yolk, albumen and shell weights than control and slow lines. However, the slow feathering line had higher egg mass, yolk mass, albumen mass and shell mass than those in the fast and control lines (Table 7.3.).

VII.4. DISCUSSION

In several studies associations have been found between the k^+ locus and other quantitative traits. With the increasing use of the K gene for day old sexing in white feather strains it has been revealed that laying performance is depressed and mortality is increased. Harris *et al.*

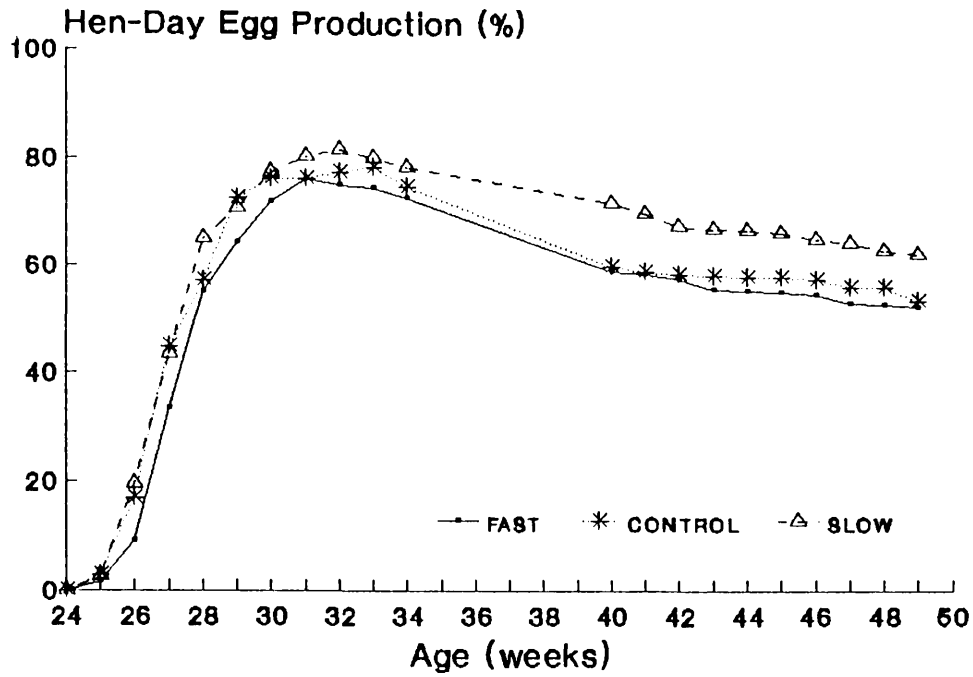


Figure 7.10. Effects of age and line on egg production (4th generation)

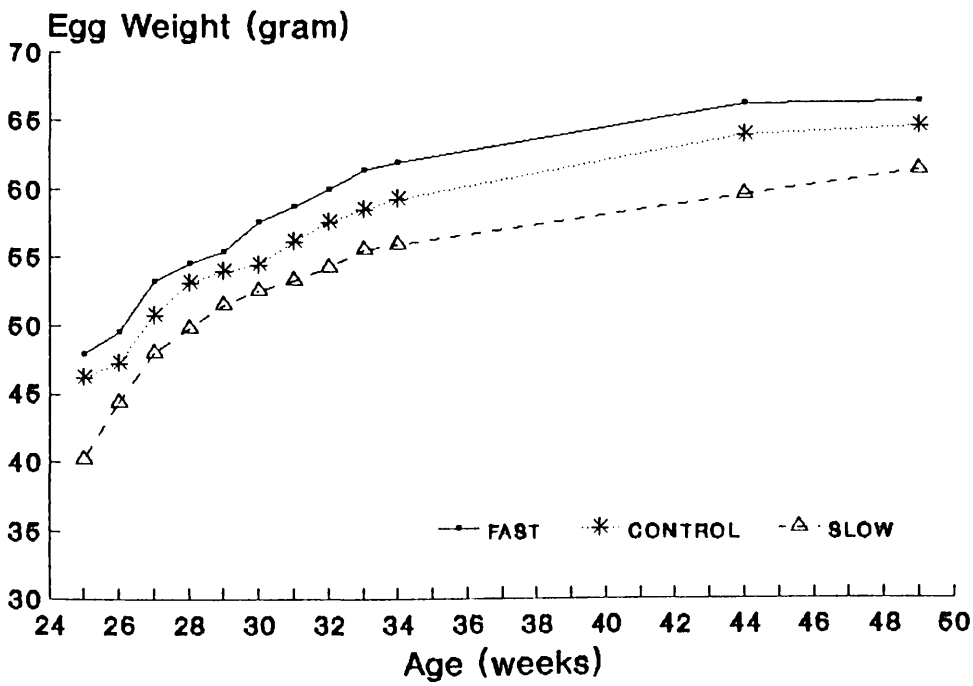


Figure 7.11. Effects of age and line on egg weight (4th generation)

Table 7.2. Effects of age and line on egg production, egg weight and egg mass.

Line	No.Bird	Age (weeks)	EPHD %	Egg Weight (gram)	Egg Mass
Fast	72	25	1.6	47.9	0.77
		26	9.1	49.5	4.50
		27	33.3	53.2	17.72
		28	55.0	54.6	30.03
		29	64.3	55.4	35.62
		30	71.8	57.6	41.36
		31	76.2	58.8	44.81
		32	75.0	60.0	45.00
		33	74.4	61.4	45.68
		34	72.6	62.0	45.01
Control	68	25	2.9	46.2	1.34
		26	17.0	47.2	8.02
		27	44.7	50.8	22.71
		28	57.1	53.1	30.32
		29	72.5	54.0	39.15
		30	76.1	54.5	41.47
		31	76.3	56.2	42.88
		32	77.3	57.6	44.52
		33	78.2	58.6	45.83
		34	74.8	59.3	44.36
Slow	70	25	2.7	40.2	1.09
		26	19.6	44.4	8.70
		27	43.3	48.0	20.78
		28	64.9	49.8	32.32
		29	70.8	51.5	36.46
		30	77.3	52.6	40.66
		31	80.2	53.3	42.75
		32	81.4	54.3	44.20
		33	80.0	55.6	44.48
		34	78.2	56.0	43.79
SED			0.88	0.25	0.53

(.....continued)

Table 7.2. (continued)

	EPHD %	Egg Weight (gram)	Egg Mass
MAIN EFFECTS			
Line - Fast	53.3	56.0	31.05
Control	57.7	53.8	32.06
Slow	59.8	50.6	31.52
SED	1.83	0.52	1.10
Age - 25	2.4	44.8	1.06
26	15.2	47.0	7.08
27	40.4	50.7	20.40
28	59.0	52.5	30.89
29	69.2	53.6	37.08
30	75.1	54.9	41.16
31	77.6	56.1	43.48
32	77.9	57.3	44.58
33	77.5	58.5	45.33
34	75.2	59.1	44.39
SED	1.00	0.29	0.60
Significance of Differences:			
Line	***	***	NS
Age	***	***	***

NS = Non Significant; *** = P < 0.001

Table 7.3. Effects of age and line on egg composition and body weight

	Age (week)	Fast	Control	Slow	SED	F-Test Significance of Differences		
						Age (A)	Line (L)	A x L
EGG COMPOSITION								
- Egg Weight (g)	44	66.38	64.06	59.72				
	49	66.69	64.76	61.52	0.75	*	***	NS
- Yolk Weight (g)	44	19.04	19.04	17.79				
	49	19.32	19.27	18.24	0.21	**	***	NS
- Albumen Wt. (g)	44	41.38	39.24	36.74				
	49	41.26	39.61	37.77	0.58	NS	***	NS
- Shell Weight (g)	44	5.96	5.78	5.19				
	49	6.12	5.87	5.51	0.11	**	***	NS
- Egg Mass (g/d)	44	36.77	37.16	39.95				
	49	34.88	34.65	38.32	0.44	***	***	NS
- Yolk Mass (g/d)	44	10.55	11.04	11.90				
	49	10.11	10.31	11.37	0.12	***	***	NS
- Albumen Ms.(g/d)	44	22.92	22.76	24.58				
	49	21.58	21.19	23.53	0.34	***	***	NS
- Shell Mass (g/d)	44	3.30	3.35	3.47				
	49	3.20	3.14	3.43	0.07	***	***	NS
BODY WEIGHT (kg)	32	3.57	3.63	3.63				
	49	3.77	3.78	3.70	0.04	***	NS	*

NS= Non Significant; * = P < 0.05; ** = P < 0.01; *** = P < 0.001

(1984) showed a higher susceptability of female progeny from slow feathering (K) dams to leucosis with the K daughter being more susceptable than k females. The work of Bacon *et al.* (1985, 1986) suggests that the increased mortality and reduced egg production is due to a linkage between the K and endogeneous proviral gene (ev-21). It is suggested that the endogeneous proviral gene interferes with the immune response of the progeny against leukosis viruses transmitted through the egg.

However, no study has reported on the effect of variations in feather growth on growth and egg production traits. In the present study, the effect of hatch on body weight and primary and secondary feather lengths will be discussed, to determine if the hatch had an influence on the differences between lines. Then the effect of line and sex on their performance will also be discussed.

Furthermore a brief view of performance comparison between the selection birds from generation 1 and generation 4 will also be discussed to see if there was an obvious effect of divergent selection.

VII.4.1. Effect of Hatch

Primary and secondary feather lengths at hatching day and selection day (25 days of age) were not affected by hatch. But, at hatching day, the body weight of fast feathering females and control males in the second hatch was found to be 2 g greater than body weight of the chickens

from the first hatch. In this case, the heavier birds were probably obtained from the bigger eggs of the older hens, although the observed differences in chick weights were much larger than the egg weights and therefore only a small contributing factor. In addition hatching eggs set were not weighed. It has been shown that chick size is directly related to the size of hatching egg from which the chick is hatched (Morris *et al.*, 1968).

VII.4.2. Effects of Line and Sex on Body Weight and Feather Lengths

The day old chicks of the fast feathering line were heavier than those of the slow feathering line. It seems that the hatching eggs of the fast line were bigger than those of the slow line. Morris *et al.* (1968) showed that a strong positive relationship between the weight of the chick at one day of age and egg weight for both males and females, the hatching weight being 66.8 per cent and 66.4 per cent of the egg weight on average respectively.

The fast feathering line still had a greater body weight up to 14 weeks of age than in the slow feathering line, however the difference between body weights at 12 and 14 weeks of age was not significant. The big differences in body weight between lines during the first few weeks of their life seems due to the differences in egg weight and hatching weight. This result was supported by Morris *et al.* (1968) who reported that body weight to 12 weeks of age was

found to be strongly related to egg weight and chick weight at one day old, though this influence declined with age. For each 1 g increment in the chick weight at day old, the 48 day weight was increased by 9 to 12 g (Morris *et al.*, 1968; Bray, 1985).

Males always had a greater body weight than the females in each line. Apparently fast feathering birds had 3 g/d (male) and 2 g/d (female) greater weight gain than the slow feathering line up to 6 weeks of age. But between 10 and 12 weeks of age, slow feathering line had a 3 g/d (male) and 4 g/d (female) greater weight gain than the fast feathering line. Between 12 and 14 weeks of age males weight gain was 23 g/d in the fast and slow lines. But the females had a much lower weight gain [1 g/d (fast line) and 5 g/d (slow line)]. The average weight gain between day old to 14 weeks of age was 24 g/d and 19 g/d in males and females respectively. There was no difference on the average rate of body weight gain between lines. Much of the sex differences were due to the allocations of feed to males and females being prepared for a hatching egg flock. Their food intake allowance were designed to achieve a target body weight. Nevertheless the line differences found could reflect the birds response to a food intake that was substantially less than *ad libitum*.

The highest rate of primary feather growth was 4 mm/day (0-2 weeks of age) and 3 mm/day (2-4 weeks of age) in fast and slow feathering lines, respectively. The highest rate of secondary feather growth was 3 mm/day between 0-4 weeks of

age (fast line) and 4-6 weeks of age (slow line). The fast feathering line had the highest rate of tail feather growth between 2-4 weeks of age (3mm/day) but in the slow feathering line it was between 8 and 10 weeks of age (2 mm/day). The rate of back and breast feathers growth was almost the same between fast and slow feathering lines. Generally, it seems that the maximum of the rate of feathering gain in the fast feathering line takes place at earlier ages than in the slow feathering line.

There were no differences in the rate of feathering gain between males and females. However females were found to have longer feathers than males. The differences in feathering between females and males are presumed to have resulted from endocrine differences. The females tending to have better feathering than the males might be explained by a differential in the activity of the thyroid gland (Glazener and Jull, 1946) or since estrogen production in the females is greater than in the males (Siegel *et al.*, 1957a).

Moult is known to take place in the growing chick as well as in the adult bird. Normally two moults take place in the domestic fowl between hatching and sexual maturity. Duerden (1910; as cited by Gericke and Platt, 1932) explained that the moult in feathers that takes place during the growing period is dependent upon age and nutrition rather than climatic conditions. Mueller and Moultrie (1952) reported that at ten weeks of 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. The first of these two moults was observed in this study. No moult was observed during the first 8 weeks of the birds life. The beginning of moult in the fast feathering line was evident at 8 weeks of age, but in the slow feathering line evidence of moult was noted at later ages.

Within all tracts there were line and sex difference in the onset and rate of completion of the moult. The most notable feature was the effect of line. Selection for slow feather growth rate in juvenile feathers also changes the age of onset of the first moult and the speed of growth of the subsequent new feathers. Examination of the Fig. 7.5-7.9 shows that the speed of completion of the moult is also slowed down. This is seen particularly well in the primary flight feathers.

VII.4.3. Egg Production, Egg Weight and Egg Mass

Fast and slow feathering birds achieved maximum rate of lay at 32 weeks of age, however, slow feathering birds had a 6 per cent higher rate of lay than the fast feathering birds, but had a smaller eggs. This result is supported by Morris *et al.* (1968) who stated that small eggs constitute a high proportion of the eggs laid by pullets. At the peak of production, control birds were intermediate between the fast and slow feathering lines. At 34 weeks of age, the fast feathering line had 3 and 6 g greater egg weight than in the

control and slow lines, respectively. There was no difference in egg mass output between lines up to 34 weeks of age. However, at 44 and 49 weeks of age, the slow feathering line had about 3 g/d greater egg mass output than the fast feathering line.

The persistency of the slow line was better than either the fast or control lines. At 49 weeks of age, the slow feathering birds rate of lay was 9 and 10 per cent higher than in the control and fast birds, respectively.

VII.4.4. Egg Composition

The average egg weight from 44 and 49 weeks of age, showed that those from the fast feathering line were about 6 g heavier than eggs from the slow feathering lines.

Yolk, albumen and shell egg weight in the fast feathering birds was 1.0, 4.0, and 0.7 g respectively greater than in the slow feathering birds. However yolk mass, albumen mass and shell mass output in the slow feathering birds were 1.3, 1.8 and 0.2 g/d respectively greater than in the fast feathering birds.

VII.4.5. The Comparison of the Performance of the Birds Between Generation 1 and 4

The performance of the birds from generation 1 (Edriss, 1988) and 4 is presented in Table 7.4, and egg production of generation 1 (Edriss, personnal communication) and 4 is

Table 7.4. The performance of fast, control and slow feathering lines from generation 1 and 4

	Line/Sex	Generation 1	Generation 4
Number of Birds	FF	212	112
	FM	208	116
	CF	144	83
	CM	126	68
	SF	235	82
	SM	199	68
Body Weight (gram)	FF	472	558
	FM	475	628
	CF	487	516
	CM	486	591
	SF	481	484
	SM	471	558
Primary Feather Length (mm)	FF	88.6 (1.00)*	103.3 (1.05)
	FM	85.5 (1.02)	104.8 (1.08)
	CF	88.5	98.2
	CM	84.0	97.2
	SF	88.3 (0.99)	84.3 (0.86)
	SM	82.5 (0.98)	74.3 (0.76)
Secondary Feather Length (mm)	FF	80.7 (1.03)	95.3 (1.14)
	FM	67.6 (1.10)	91.9 (1.22)
	CF	78.7	83.4
	CM	61.6	75.2
	SF	76.9 (0.98)	61.2 (0.73)
	SM	58.5 (0.95)	47.1 (0.63)
Tail Feather Length (mm)	FF	34.5 (1.14)	60.7 (1.52)
	FM	19.8 (1.05)	45.5 (1.94)
	CF	30.2	40.0
	CM	18.8	23.4
	SF	27.2 (0.90)	22.2 (0.55)
	SM	16.9 (0.90)	12.9 (0.55)
Back Feather Score	FF	5.0	5.7
	FM	3.3	5.2
	CF	4.6	4.9
	CM	2.7	3.7
	SF	4.3	3.7
	SM	2.5	2.4

FF= Fast Female; FM= Fast male; CF=Control Female; CM= Control Male; SF=Slow Female; SM= Slow Male

* Data in parenthesis indicate the values, within sex and generation, as a proportion the control. This allow a comparison between generation independent of body weight.

shown in Table 7.5.

After 4 generations of selection, on average, males and females of the fast feathering line gained +7.6 and 5.1 mm of primary feather length; +16.7 and 11.9 mm of secondary feather length; +22.2 and +20.7 mm tail feather length; +1.49 and +0.84 units of back score; and +37 and +42 g of body weight, while the males and females of slow group lost -22.9 and -13.9 mm of primary feather length; -28.1 and -22.2 mm of secondary feather length; -10.5 and -17.8 mm of tail feather length; -1.35 and -1.22 units of back score; and -33 and -32 g of body weight compared to the control line. From the gain and loss of feather lengths, it is clear that tail feathers responded more than the other feathers. This is not surprising since the selection of these birds was based on predicted tail feather lengths. However, the slow line responded more than the fast line. It is also evident that secondary feathers are more responsive to selection than the primary feathers. Krogseth and Ukkelberg (1955) reported that slow feathering can be detected at day old if the length of secondary number two is less than 6 mm. Siegel *et al.* (1957b) 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.

It seems that divergent selection had a more pronounced effect in the males than in the females. This is not surprising since the intensity of selection is greater in the males.

Table 7.5. Egg production of fast, control and slow feathering lines from generation 1 and 4

Line	Age (weeks)	Generation 1 EPHD %	Generation 4 EPHD %
Fast	23	1	0
	24	6.8	0
	25	22.8	1.6
	26	45.7	9.1
	27	67.1	33.3
	28	70.7	55.0
	29	73.2	64.3
	30	72.8	71.8
	31	77.2	76.2
	32	75.2	75.0
	33	78.1	74.4
	34	79.3	72.6
Control	23	0	0
	24	5.3	0
	25	24.8	2.9
	26	47.0	17.0
	27	64.7	44.7
	28	77.7	57.1
	29	78.9	72.5
	30	76.9	76.1
	31	78.4	76.3
	32	76.2	77.3
	33	76.8	78.2
	34	75.6	74.8
Slow	23	0	0
	24	4.2	0
	25	14.6	2.7
	26	39.4	19.6
	27	56.0	43.3
	28	68.4	64.9
	29	72.9	70.8
	30	73.5	77.3
	31	74.0	80.2
	32	75.3	81.4
	33	77.1	80.0
	34	76.7	78.2

One factor that may influence the response to slower feather growth is that the broiler lines from which this stock originates would have 10-15 generations of selection for body growth rate and other characters which would have include feather growth at times. It would be expected that a response to slower growth would be easier to obtain then the reverse.

The changes in egg production and egg weight suggests that selection for slow feather growth has a pleiotropic effect on reproductive traits. However, since the lines were not replicated the differences observed could have been environmental in origin. Continuation of this difference into the 5th and 6th generation would make the genotypic origin for the line effect more convincing.

CHAPTER VIII. EXPERIMENT 5:

LINE CROSSING

VIII.1. INTRODUCTION

Two series of alleles of major genes, k and t, influence feathering of chickens. The k series is sex-linked and the t series are autosomal genes. Since this study involves the k alleles, therefore only this allele series will be reviewed. The k series consists of k^+, K, K^s and K^n alleles which express different rates of feathering ranging from rapid to extremely slow feathering.

Producers of commercial broiler breeding stock frequently use the sex-linked genes for rate of feathering to produce chicks that can be sexed by the relative lengths of the primary and covert wing feathers. In the production of feather-sexable commercial broiler chicks the fast feathering sires (kk) and slow feathering dams (K-) are used.

Two experiments were conducted to investigate if two major genes were segregating in the fast and slow feathering lines. Therefore the various matings were carried out. As the control of the first experiment, the Marshall's broiler breeder in which the male was fast feathering (kk) and the female was slow feathering (K-) were involved. Since the first study involved 8 various matings not many offspring per mating group were obtained, therefore the second experiment of line crossing was carried out to get more offspring and to focus on only two matings, viz. Fast Male x

Slow Female, and Slow Male x Fast Female.

VIII.2. MATERIALS AND METHODS

VIII.2.1. Experimental Design

The experimental design used was 2 x 8 factorial for experiment 1 test crossing and 2 x 2 factorial design for experiment 2 test crossing, with male and female parents of the lines giving eight and two crossings in experiments 1 and 2, respectively.

VIII.2.2. Birds and Management

a. Line Crossing I

In each line, a total of nine potential males and nine potential females of the fourth generation of fast and slow feathering lines (Ross' broilers) were used for the various matings. In addition, six Marshall's broiler males and six Marshall's broiler females were also used. Therefore one male was mated to one female. Twice weekly matings were carried out by artificially inseminating each hen with semen from a specific sire.

The genes for feather growth (not of the k^+ or t^+ allele series) in the fast and slow lines were labelled **F** and **S**, respectively, so that in the progeny the parental origin of the genes are seen. The breeding company origin was noted by a **m** and **r** notation representing Marshall and

Ross respectively.

The various matings made for the study were as follows:

Mating	Parents			Progeny	
1 :	Marshall Male	by	Fast Female		
	kkFmFm	x	K-FrFr	KkFmFr	k-FmFr
2 :	Marshall Male	by	Slow Female		
	kkFmFm	x	K-SrSr	KkFmSr	k-FmSr
3 :	Fast Male	by	Marshall Female		
	KKFrFr	x	K-FmFm	KKFrFm	K-FrFm
4 :	Fast Male	by	Fast Female		
	KKFrFr	x	K-FrFr	KKFrFr	K-FrFr
5 :	Fast Male	by	Slow Female		
	KKFrFr	x	K-SrSr	KKFrSr	K-FrSr
6 :	Slow Male	by	Marshall Female		
	KKSrSr	x	K-FmFm	KKSrFm	K-SrFm
7 :	Slow Male	by	Fast Female		
	KKSrSr	x	K-FrFr	KKSrFr	K-SrFr
8 :	Slow Male	by	Slow Female		
	KKSrSr		K-SrSr	KKSrSr	K-SrSr

The eggs from each individual hen were collected daily for 18 days on the basis of their line. At hatching day, the chicks were vent-sexed, and housed on 2nd November 1989.

b. Line Crossing II

In each line, a total of eight males and 48 females were used for two matings. Therefore one male was mated to six females. Twice weekly matings were carried out by artificially inseminating each hen with semen from a specific sire. The matings made for the study were as follows:

Mating	Parents			Progeny	
1 :	Fast Male	by	Slow Female		
	KKFrFr	x	K-SrSr	KKFrSr	K-FrSr
2 :	Slow Male	by	Fast Female		
	KKSrSr	x	K-FrFr	KKSrFr	K-SrFr

For two weeks the eggs from each individual hen were collected daily on the basis of their line. On hatching day, the chicks were vent-sexed, and were housed on 11th January 1990.

VIII.2.3. Housing

280 chicks from the line crossing I were kept in a battery brooder up to 15 days old, while 418 chicks of line crossing II were raised in a floor pen. The heat in the pen was supplied by electric brooders and the brooding temperature was initially 32^{o}C decreasing steadly to 24^{o}C at 15 days old.

VIII.2.4. Diets

The chicks were given a commercial starter diet (CP= 230 g/kg; ME= 12.6 MJ/kg). The diets and water were offered *ad libitum*.

VIII.2.5. Recording Procedures

At fourteen days of age, feathering measurements and body weight were recorded. The feather measurements were carried out for:

- primary and secondary wing feathers
- tail feathers

The methods for measuring those feathers can be seen in Chapter III.

VIII.3. RESULTS

The mean body weights and feather measurements from the eight crosses in Line crossing 1 and 2 are presented in Table 8.1. The analyses of variance indicated that there were very highly significant main effects and interactions in both line crossings for primary, secondary, tail and back feather lengths.

The examination of effects of the sire and dam genotypes on body weights and feather lengths is carried by arranging the results according to sire: Marshall, Fast and Slow and within sire for dam: Marshall, Fast and Slow. There was however no Marshall x Marshall as the mating plan was not a complete three sires x three dams factorial.

Table 8.1. Effect of line crossing on the performance of the progeny at 14 days of age

Mating	Sex	n	Body Weight (gram)	Primary Feather Length (mm)	Secondary Feather Length (mm)	Tail Feather Length (mm)	Back Feather Length (mm)	Back Feather Score
Line Crossing 1:								
MrM x FF	F	15	229.4	66.0	59.1	31.4	6.5	1.7
	M	21	243.0	61.3	42.6	14.9	2.7	1.2
MrM x SF	F	16	208.9	64.5	56.6	29.8	6.6	1.6
	M	14	206.2	26.4	18.1	2.6	0.0	1.0
FM x MrF	F	16	218.7	62.8	46.6	16.3	5.0	1.4
	M	17	233.5	54.2	37.8	11.7	2.3	1.0
FM x FF	F	17	214.2	61.7	44.1	15.8	3.7	1.3
	M	15	216.1	57.1	38.9	11.9	2.5	1.0
FM x SF	F	18	202.6	56.6	37.9	11.3	3.2	1.3
	M	15	203.7	32.1	23.6	3.4	0.0	1.0
SM x MrF	F	18	210.8	36.6	25.9	3.8	0.3	1.0
	M	15	216.9	30.4	24.5	4.1	0.0	1.0
SM x FF	F	18	209.3	39.8	26.3	4.9	0.2	1.0
	M	16	212.6	34.9	24.8	6.1	0.4	1.0
SM x SF	F	16	193.3	28.5	17.8	1.8	0.2	1.0
	M	14	198.2	21.9	14.3	1.6	0.0	1.0
SED			7.05	2.85	2.27	1.23	0.57	0.10
CV (%)			9.50	17.70	19.30	32.80	77.20	26.00
Line Crossing 2:								
FM x SF	F	140	245.5	58.9	39.1	14.0	4.3	1.8
	M	103	253.9	42.8	27.0	5.5	0.9	1.1
SM x FF	F	101	256.7	44.7	28.2	9.9	2.8	1.1
	M	74	270.5	39.3	24.5	5.0	1.0	1.0
SED			3.96	1.54	1.30	0.67	0.37	0.09
CV (%)			10.80	22.20	29.30	50.30	102.90	40.30
Significance of Differences								
Line Crossing 1 :								
Cross (C)			***	***	***	***	***	***
Sex (S)			*	***	***	***	***	***
C x S			NS	***	***	***	***	***
Line Crossing 2 :								
Cross (C)			***	***	***	***	***	***
Sex (S)			***	***	***	***	***	***
C x S			NS	***	***	***	***	*

FF= Fast-Female; FM= Fast-Male; MrF=Marshall-Female; MrM= Marshall Male;
SF= Slow-Female; SM= Slow-Male

VIII.3.1. Body Weight

The sex difference in body weight was greatest when Marshall and Fast were crossed (Table 8.2). With all other crosses sexual dimorphism was reduced. When the Slow dam was used in a cross the sexual dimorphism was less than that when the Slow sire was used in a cross.

Both the Fast and Slow sires produced progeny which were lighter than the Marshall progeny and the Slow sire male were worst in this respect. Within dams the Slow dam was always inferior to Marshall and Fast dams. In both test crosses the Slow sire x Fast dam produced a better body weight than the reciprocal cross.

VIII.3.2. Feather Length

a. Line Crossing 1

a.1. Females

The female progeny offer the more straightforward genotype to examine for the effects of major and minor genes. The back feathers were not included in this analysis. The data from line cross 1 are presented first (Table 8.3, Fig. 8.1.).

The k gene with a Fast feathering genotype from the sire and dam produced, as expected the fastest feather growth. The substitution of the fast feathering dam (K-FrFr) by a Slow feathering dam (K-SrSr) decreased primary (P), secondary (S) and tail (T) growth slightly. This may be

Table 8.2. Body weight of progeny at 14 days

Parents Genotype		Progeny Genotype		Body Weight g Male	Female
Male	Female	Male	Female		
Line Cross 1					
1] kkFmFm x K-FrFr		KkFmFr	k-FmFr	243.0	229.4
2] kkFmFm x K-SrSr		KkFmSr	k-FmSr	206.2	208.9
3] KKFrFr x K-FmFm		KKFrFm	K-FrFm	233.5	218.7
4] KKFrFr x K-FrFr		KKFrFr	K-FrFr	216.1	214.2
5] KKFrFr x K-SrSr		KKFrSr	K-FrSr	203.7	202.6
6] KKSrSr x K-FmFm		KKSrFm	K-SrFm	216.9	210.8
7] KKSrSr x K-FrFr		KKSrFr	K-SrFr	212.6	209.3
8] KKSrSr x K-SrSr		KKSrSr	K-SrSr	198.2	193.3
Line Cross 2					
9] KKFrFr x K-SrSr		KKFrSr	K-FrSr	253.9	245.5
10] KKSrSr x K-FrFr		KKSrFr	K-SrFr	270.5	256.7

Table 8.3. Female feather lengths in line cross 1

Parents Genotype	Progeny Genotype	Feather Lengths mm Primary	Secondary	Tail
1] kkFmFm x K-FrFr	k-FmFr	66.0	59.1	31.4
2] kkFmFm x K-SrSr	k-FmSr	64.5	56.6	29.8
3] KKFrFr x K-FmFm	K-FrFm	62.8	46.6	16.3
4] KKFrFr x K-FrFr	K-FrFr	61.7	44.1	15.8
5] KKFrFr x K-SrSr	K-FrSr	56.6	37.9	11.3
6] KKSrSr x K-FmFm	K-SrFm	36.6	25.9	3.8
7] KKSrSr x K-FrFr	K-SrSr	39.8	26.3	4.9
8] KKSrSr x K-SrSr	K-SrSr	28.5	17.8	1.8

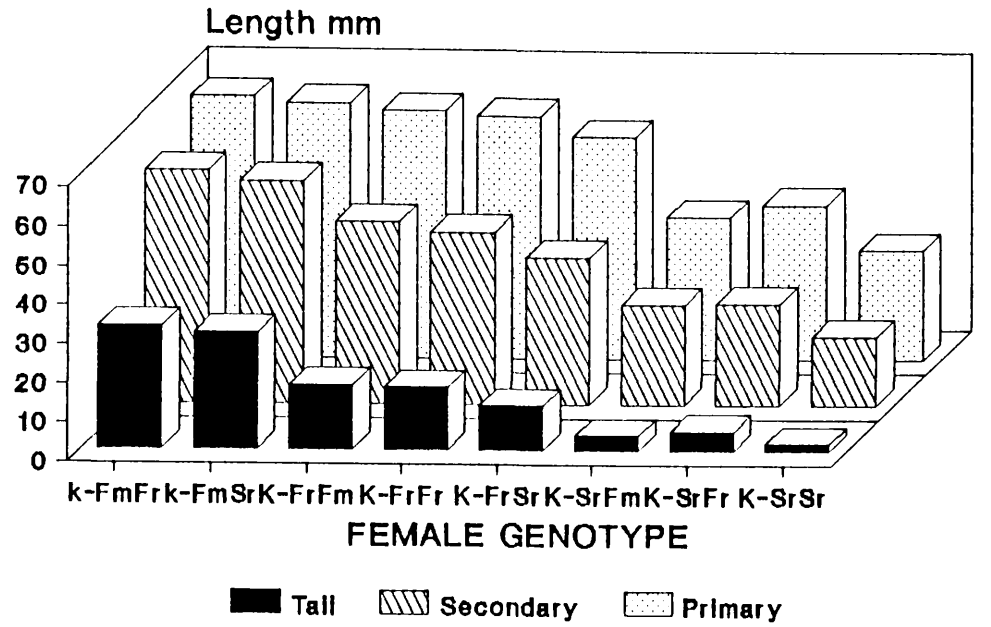


Figure 8.1. Feather genotype analysis of females progeny of line cross 1 (14 day length)

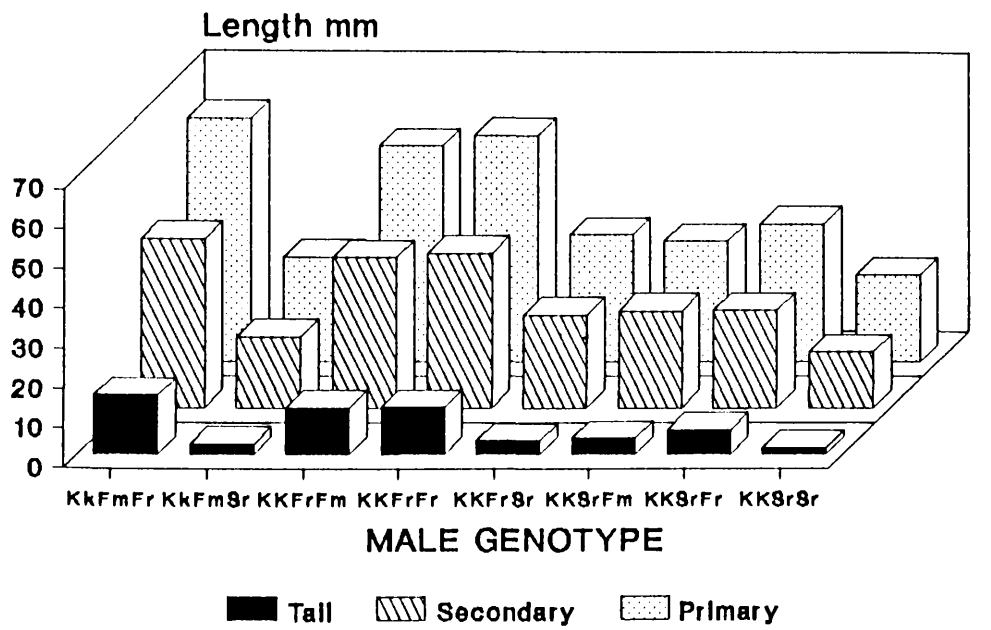


Figure 8.2. Feather genotype analysis of males progeny line cross 1 (14 day length)

regarded as illustrating the growth depressing effects of minor genes (Sr) (independantly of the K gene) from one parent on a Fast feathering background. Using a Slow feathering dam decreased P, S and T growth by about 2 mm.

Substitution of the fast gene k by the slow gene K by using a Fast feathering (Fr) sire had a greater effect on S and T growth (k-FF v K-FF) than on P growth. This may be regarded as illustrating the growth depressing effect of the K gene from the fast line.

Replacement of a Fm dam by a Fr dam (cross 4 v cross 5) had only a slight effect on feather growth. This may be regarded as illustrating the growth effects of minor genes (Sr) (independantly of the K gene) on a Slow feathering background. Using a Slow feathering dam decreased P, S and T growth by about 5 mm. These three separate effects are illustrated by the first five female genotypes shown in Fig. 8.1.

In the crosses 1-5 the K gene in the female progeny originates from sires which are fast feathering. When a Slow feathering sire is used the K gene in the female progeny originates from a Slow sire. Progeny from crosses 3 and 4 differ from those of 6 and 7 by possessing a K gene from a Slow sire and Sr genes. From above the Sr genes were calculated to depress feather growth by about 5 mm. The addition of the K gene from a Slow sire can thus be quantified by comparing the lengths of feathers in crosses 3 and 4 with 6 and 7. Performance in crosses 6 and 7 includes the effects of a K of male origin and Sr genes. By adding

the depressing effect of the Sr gene (5mm on average) to the P, S and T lengths in cross 6 and 7 the Sr effect is removed and the effect of a 'slow' K can be estimated. By this method a growth retardation value of 13.8 mm for the 'slow' K is calculated. Finally the combined effect of two sets of Sr genes and a 'slow' K in seen in cross 8. There is clearly some interaction of gene effects because the addition of another Sr adds more than another 5 mm depression. Indeed the interaction produces an average depression of about 7.5 mm.

a.2. Males

The feather lengths of the male progeny for matings 1-8 are presented in Table 8.4 and Fig. 8.2.

The genotype of all males differ from the females only in respect of an additional K gene originating from the dam. The first mating produced the fastest feathering males. In matings 3 and 4 the k gene was replaced with a K gene from a fast feathering sire. The female results indicated that the Marshall dam and the Fast dam gave daughters with similar feather growth. The same similarity in growth is evident in the sons. It seems reasonable to state that the principal difference between the males from mating 1, with the heterozygous Kk, and those from matings 3 and 4, is due to the homozygous KK depressing feather growth.

In mating 2 the male offspring carry a K gene from a Slow dam and the slow feathering Sr genes. It was noted in the female progeny results that the Sr genes alone was estimated to produce a depression of 5 mm while the K gene,

Table 8.4. Male feather lengths in line cross 1

Parents Genotype	Progeny Genotype	Feather Lengths mm Primary	Secondary	Tail
1] kkFmFm x K-FrFr	kKFmFr	61.3	42.6	14.9
2] kkFmFm x K-SrSr	kKFmSr	26.4	18.1	2.6
3] KKFrFr x K-FmFm	KKFrFm	54.2	37.8	11.7
4] KKFrFr x K-FrFr	KKFrFr	57.1	38.9	11.9
5] KKFrFr x K-SrSr	KKFrSr	32.1	23.6	3.4
6] KKSrSr x K-FmFm	KKSrFm	30.4	24.5	4.1
7] KKSrSr x K-FrFr	KKSrSr	34.9	24.8	6.1
8] KKSrSr x K-SrSr	KKSrSr	21.9	14.3	1.6

Table 8.5. Male and female feather lengths in line crosses 1 and 2, matings 5 and 7, and 9 and 10

Parents Genotype	Progeny Genotype	Feather Lengths mm/100g BW Primary	Secondary	Tail
Females				
5] KKFrFr x K-SrSr	K-FrSr	27.9	18.7	5.6
7] KKSrSr x K-FrFr	K-SrFr	18.6	12.6	2.3
9] KKFrFr x K-SrSr	K-FrSr	24.0	15.9	5.7
10] KKSrSr x K-FrFr	K-SrFr	17.4	11.0	3.9
Males				
5] KKFrFr x K-SrSr	KKFrSr	15.8	11.6	1.7
7] KKSrSr x K-FrFr	KKSrFr	16.4	11.7	2.9
9] KKFrFr x K-SrSr	KKFrSr	16.9	10.6	2.2
10] KKSrSr x K-FrFr	KKSrFr	14.5	9.0	1.8

coming from a fast parent, depressed growth by nearly 14 mm. There is clearly an interaction between the genes affecting feather growth in the Marshall sire and those in the Slow dam. There was an average depression over the three feathers of nearly 24 mm. The separate effects of the Sr and K genes in the female amount to about 19 mm. Thus there is a further depression of about 5 mm due to the interaction. In mating 5 the decrease in average length, due to K and Sr, from that in mating 1 is nearly 21 mm. This is very similar to the combined effect of Sr and K in the females. The effects of K and Sr from different sources are quite consistent across three genotypes, i.e. from matings 5, 6, and 7. The average difference between the feather length in mating 1 and those in 5, 6 and 7 is 19.2 mm, almost exactly the combined effect of K and Sr in female progeny. Another Sr and a K from a slow feathering parent in mating 8 saw another depression of length by more than that expected from Sr alone.

b. Line Crossing 2

The growth of progeny in cross 2 was slightly better than similar genotypes in cross 1. Thus feather lengths among genotypes were compared on the basis of relative length per 100 g body weight. The results of this calculation are presented in Table 8.5. The differences observed in cross 1 between female progeny from fast (KKFrFr) and slow (KKSrSr) sires were repeated in cross 2. The average depression of length in cross 1 caused by the reciprocal cross was 6.2 mm/100 g body weight whereas in

cross 2 it was 4.4 mm/100 g body weight. The KKSrSr male is introducing to the female progeny a gene with the same feather growth depressing effect gene in a repeated experiment. The feather growth of all male progeny was similar in cross 1 and cross 2.

VIII.4. DISCUSSION

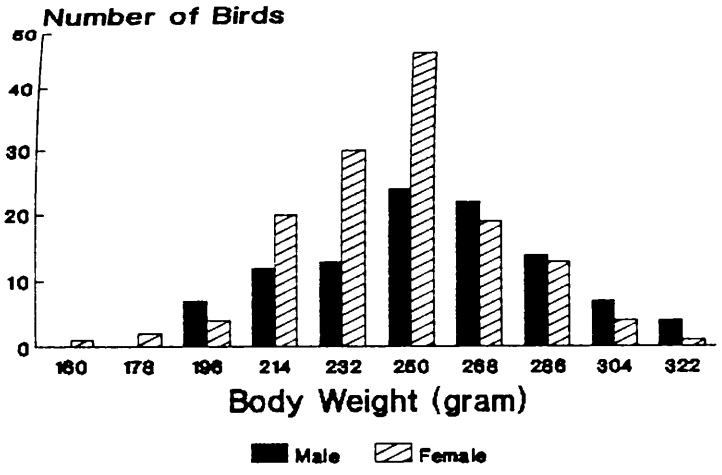
Selection for slow and fast feather growth in these lines was expected to produce differences in growth rate as a result of the quantitative effects of minor genes. The feather growth of some progeny from the Slow line was so slow that it appeared some minor or a major gene was present in the Slow line that was causing a substantial reduction in feather growth. These two line crosses were carried out to investigate the possibility that the selection process had increased the frequency of a modified K gene giving slower growth. If this were the situation then males in the Slow line might be expected to be heterozygous for the 'slow' K. If the suggested mutation had taken place then some males of the slow line could be $K^{S}K$, where K^{S} is one of the allelic series, and females could be either K- or K^{S}-.

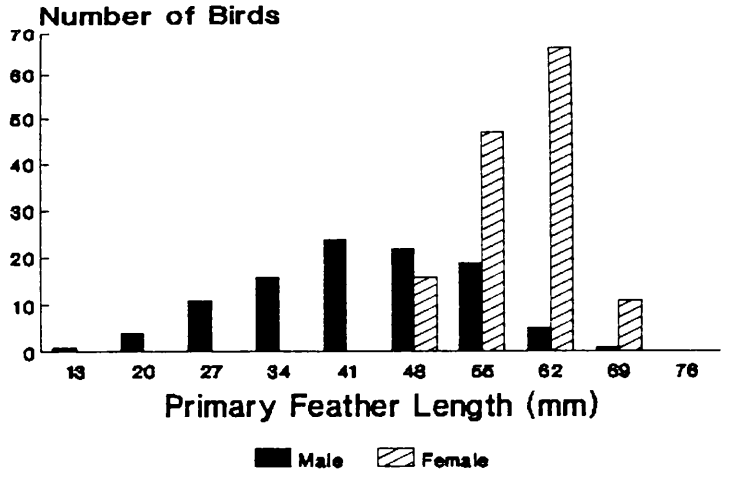
If this were the case then female progeny from Fast males would be expected to show a normal distribution of feather lengths with a single modal. If the female progeny from Slow males were segregating at the K locus then a bimodal distribution would be expected. The distribution of body weights and lengths of primary, secondary, and tail

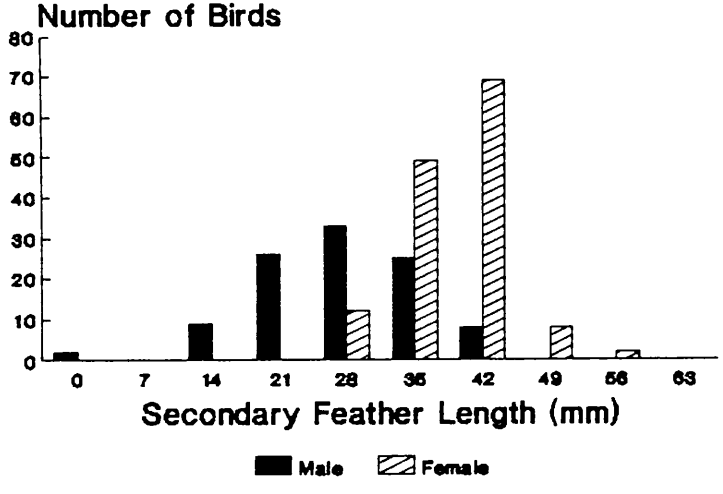
feathers of the male and female progeny from the reciprocal matings in line cross 2 are shown in Figs. 8.3 and 8.4.

The female progeny from Slow sires show a distinct bimodal distribution of feather growth. So do the males but to a lesser extent. In the Fast male x Slow female progeny a proportion of the male progeny, but not the female progeny, must carry either the K^S or another gene inducing the slow growth. However the effect of the 'K^S' in the KsKFrSr male is not sufficient to cause a clear bimodal distribution in the primary and secondary feathers but there is suggestion that it is present in the tail feathers.

Therefore the evidence presented suggests that the a major gene or genes on the sex chromosome may be have been modified or increased in frequency by the selection process so that in the Slow sires the alleles are segregating. The K^S gene was not assumed to be present in the original foundation stock from which the three lines have been produced. Over the five generations it is conceiveable that the $K > K^S$ mutation may have taken place and selection in the fast line removed them from the population, but selection in the slow line favoured those birds carrying the gene. Selection for fast feather growth over four generations has produced some females at day old each generation that exhibited the typical k fast flight feather growth. The frequency of these females at hatching was about 0.1 per cent. These females were discarded. However the selection process may have lead to an increased frequency of the K^S gene and that gene may now be segregating with K to







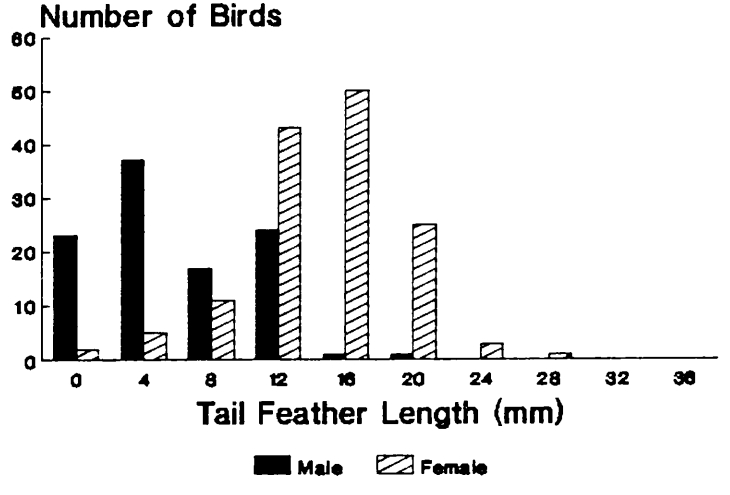


Figure 8.3. The distribution of body weights and lengths of primary, secondary, and tail feathers of the male and female progeny from line cross 2 (Fast Male x Slow Female)

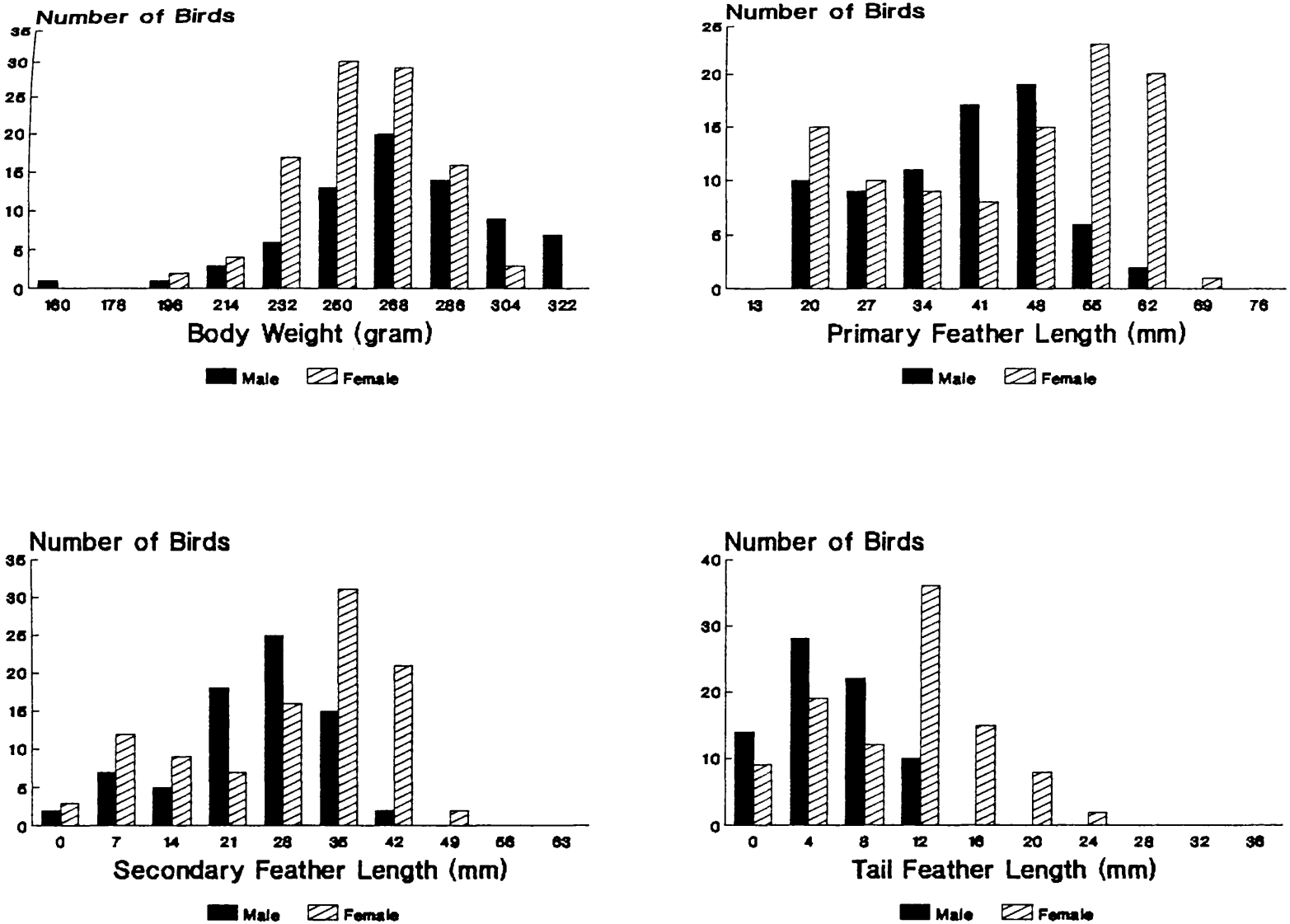


Figure 8.4. The distribution of body weight and lengths of primary, secondary, and tail feathers of the male and female progeny from line cross 2 (Slow Male x Fast Female)

cause the observed effects in feather growth.

CHAPTER IX. EXPERIMENT 6:

PROTEIN DEPOSITION

IX.1. INTRODUCTION

The economic viability of broiler industry depends upon the availability of efficient broiler stock. Brody (1935) predicted that low efficiency strains would store less protein and more fat than high efficiency strains. Chwalibog *et al.* (1978), underlined the fact that increasing growth capacity is accompanied by more efficient energy utilisation. Furthermore, Jorgensen *et al.*(1990) reported that a growth selected line had a greater energy efficiency than an efficiency selected line. However, they concluded that selection for high efficiency resulted in birds with much leaner carcasses than birds selected for high growth rate.

It is important to know the relative efficiencies of the fast and slow feathering lines. The slow feathering line have less feathers than fast feathering line. Since feathers play a role in conserving heat, therefore for commercial poultry, the slow feathering birds would incur cost in terms of feed and controlled environment. Certainly there could be a possible saving too, since feathers contain a high level of protein, and dietary requirements of this nutrient could possibly be modified. Furthermore, it is probable that the fast feathering line used more protein for their feathers and slow feathering line were able to use more protein for other tissues since they have less

feathers.

An experiment was conducted to determine the protein deposition in feathers, meat and whole carcass (without meat) of males and females of fast and slow feathering lines at different body weights. To determine whether a difference in feathering existed in the broilers due to the presence of fast and slow feathering genes, therefore feather weight and feather lengths were recorded. The effect of age, line and sex on rectal, skin and feather surface temperature and thermal resistance of the feathers were also studied.

IX.2. MATERIALS AND METHODS

IX.2.1. Experimental Design

This experiment followed a 4 x 2 x 6 factorial design. The three factors were lines, sexes, and body weights. Two replicates were used and duplicate sub-samples were used for protein analysis.

IX.2.2. Birds and Management

One day old chicks were obtained from the fourth generation of fast and slow feathering lines. Approximately 480 chicks as hatched of these lines were used. The chicks hatched together with the chicks for the line crossing 1 experiment (experiment 5) on 2nd November 1989. The chicks

were vent-sexed, wing banded and weighed. They were raised in a battery brooder from one day old to 15 days of age. After this age, the chicks were moved into one floor pen (7.5 cm/bird) in an environmentally controlled room. The birds of line crossing I, Fast x Slow and Slow x Fast used as control 1 and control 2 lines, respectively. They were also moved from the battery brooder into another floor pen.

The brooding temperature in the battery was about 32°C. While the temperature in the pen was 25°C at 15 days of age and decreased steadily to 21°C at 21 days of age. Thereafter it was attempted to maintain temperature constantly at 21°C until the end of experiment.

IX.2.3. Diets

The chicks were given a commercial starter diet (CP= 230 g/kg; ME= 12.6 MJ/kg) during 0-4 weeks of age. Thereafter, the birds were given a commercial grower diet (CP= 195 g/kg; ME= 13.5 MJ/kg) until 8 weeks of age.

IX.2.4. Recording Data

a. Skin and Surface Temperature

Skin temperature was measured by contact thermometer (Solomat MPM 500) and surface temperature of feathers was measured by a radiometer (Instatherm) on the back. Ambient and surroundings temperature were measured using a Solomat MPM 500 and a radiometer (Instatherm), respectively.

b. Thermal Resistance of the Feathers

Thermal resistance of the feathers (r_f) was calculated as:

$$r_f = \left[\frac{(T_f - T_o)}{r_r} + \frac{(T_f - T_a)}{r_c} \right]^{-1} \times (T_s - T_f)$$

where r_f = Thermal resistance of the feathers (s/cm)

T_f = Surface temperature of the feathers (^oC)

T_o = Radiative temperature of surrounding (^oC)

T_a = Temperature of air (^oC)

T_s = Temperature of skin (^oC)

r_r = Equivalent radiation resistance (s/cm)

r_c = Resistance to convection (s/cm)

It is assumed that the values for equivalent radiation resistance (r_r) and resistance to convection (r_c) are 3.7 and 2.3 s/cm, respectively (C.Wathes, personal communication). The thermal resistance of the feathers (r_f) is a derived trait which measures resistance to heat loss and has been shown to be linearly related to feather cover. (For further details see Appendix 13).

c. Feathers and Carcass Weight Determination

For each line and each sex, two chicks were killed at the weights of around 150, 280, 400, 600, 1100 and 1900 grams. After being fasted for 18 hours, they were individually weighed and killed with carbon dioxide. Following a water scald, feathers from individual birds were

removed, placed in weighed muslin bags, and dried in a domestic clothes drier.

The whole carcass weights were recorded. Meat was stripped from the carcass and weighed separately.

d. Dry Matter and Protein of Meat, Whole Carcass (Without Meat) and Feathers

The carcass and meat from it was chopped and minced in a mixing bowl for about 20 minutes for thorough mixing, cleaning the bowl between meat/carcasses. A representative sample (about 100 g) of each mince was dried in an aluminium container in a freeze drier for 72 hours. The dried samples were weighed and stored in plastic bags at $-20^{o}C$. Each frozen mince was reground with liquid nitrogen at low speed to prevent fat from melting. The milled samples were used for analysis of crude protein (see procedure of protein determination).

The dried feathers from each bird were cut with a pair of scissors to get fine feathers suitable for analysis. A representative sample (1 gram) of each fine cut feathers was dried in plastic cup with its cover slightly open in a freeze drier for 24 hours. These dry samples were ready to be used for analysis of crude protein (see procedure of protein determination).

e. Protein Determination

The method used for protein determination was the "indophenol blue method" which involves digestion of protein to ammonia (NH_3), followed by colorimetric quantification of the ammonia (Spillane, 1966). The chemicals were used as follows:

- Sulphuric acid reagent: 40 g Selenium dioxide + 100 ml distilled water + 2 litres concentrated sulphuric acid.
- Hydrogen peroxide: 100 volume strength
- Reagent (A+B): 31.26 g phenol + 3.75 g sodium hydroxide + 0.156 g sodium nitroprusside made up to 5 litres with distilled water.
- Reagent C: 99.4 g trisodium orthophosphate + 11.69 g disodium hydrogen orthophosphate + 15.6g sodium hydroxide + 31.2 ml sodium sodium chlorite made up to 2.5 litres with distilled water.

e.1. Procedure Determination of Protein in Meat and Carcass

Crude protein was determined on duplicate 1.00 g samples. One gram of all milled samples as weighed into a 250 ml digest tube, 22.5 ml of sulphuric acid reagent was added and the acid was allowed to wet the sample thoroughly. Then, 9 ml of hydrogen peroxide was added in 3 ml aliquots. The reaction was allowed to subside and then placed in a digester block (Tecator) at $34^{o}C$. The samples were digested for 60 minutes and when the solution was clear, it was allowed to cool and made up to a volume of 225 ml with

water. When solution was still dark, 1 ml of hydrogen peroxide was added and re-digested for 15 minutes. The solution was then mixed and allowed to cool. The solution was now ready for the colorimetric procedure.

An amount of 5 ml of digest solution was diluted with 10 ml H_2SO_4 10%. Thereafter, 0.05 ml of this solution was diluted with 10 ml of reagent (A+B), 5 ml of reagent C added and the whole mixed thoroughly and allowed to sit for 60 minutes at room temperature. Standard solutions of 0.01, 2.77 and 5.54 ug/ml of protein concentrations were diluted at the same time as the samples. When the indophenol blue colour has developed, the solutions were read on the spectrophotometer at 584nm.

e.2. Procedure Determination of Protein in Feathers

The procedure for determination of protein in feathers was almost the same as that for the meat or carcass. But 75 ml digest tubes were used and therefore only 7.5 ml of sulphuric acid reagent and 3 ml of hydrogen peroxide in 1 ml aliquots were added. After the sample was digested (solution was clear), it was allowed to cool and made up to a volume of 75 ml.

IX.3. RESULTS

IX.3.1. Skin and Surface Temperature

The skin and surface temperature were affected by age, line and sex. The fast feathering line had higher skin temperature than the slow feathering line, but feather surface temperatures were the opposite. Generally, females had higher skin temperatures but lower feather surface temperatures than males (Table 9.1).

IX.3.2. Thermal Resistance of the Feathers

The thermal resistance of the feathers were affected by age, line and sex (Table 9.1.). When the birds become older, the thermal resistance of the feathers increased. The fast feathering line had a higher thermal resistance than slow feathering line. For example, at 28 days of age the difference in thermal resistance of feathers between fast and slow feathering lines was approximately 2.0. In general, females had higher thermal resistance of the feathers than males.

IX.3.3. Body Composition

Body composition data are summarised in Table 9.2. Live body weight, defeathered body weight and feather weight were affected by age, line and sex. Fast feathering birds

Table 9.1. Effects of age, line and sex on back skin and feather surface temperatures and thermal resistance of the feathers

Line/ Sex	Age	Temperature				Thermal Resistance of Feathers (r_f) s/cm
		Surrounding	Ambient	Feather Surface	Back Skin	
	(Days)	°C	°C	°C	°C	
FF	10	22	24.0	33.5	39.4	0.78
	18	20	25.7	33.5	39.3	0.73
	22	21	22.8	29.5	38.9	1.82
	28	20	21.8	27.5	39.1	2.44
	37	18	20.4	25.0	39.2	3.31
	49	18	19.8	24.0	39.1	4.03
FM	10	22	24.0	33.5	39.2	0.76
	18	20	25.7	34.0	39.1	0.61
	22	21	22.8	31.0	38.7	1.17
	28	20	21.8	28.0	39.1	2.15
	37	18	20.4	25.5	39.0	2.94
	49	18	19.8	23.5	39.0	4.64
SF	10	22	24.0	33.5	39.3	0.76
	18	20	25.7	34.0	39.3	0.63
	22	21	22.8	33.5	38.7	0.62
	28	20	21.8	34.0	38.6	0.50
	37	18	20.4	29.0	38.5	1.46
	49	18	19.8	29.0	38.8	1.85
SM	10	22	24.0	33.5	39.1	0.74
	18	20	25.7	34.0	39.1	0.61
	22	21	22.8	34.0	38.6	0.54
	28	20	21.8	34.5	38.5	0.41
	37	18	20.4	34.5	38.0	0.32
	49	18	19.8	30.5	38.6	1.22
CF1	10	22	24.0	34.0	39.3	0.66
	18	20	25.7	33.5	39.3	0.73
	22	21	22.8	31.0	39.0	1.34
	28	20	21.8	29.0	39.0	1.75
	37	18	20.4	25.5	39.1	2.94
	49	18	19.8	23.5	39.2	4.70
CM1	10	22	24.0	33.5	39.3	0.76
	18	20	25.7	34.0	39.3	0.63
	22	21	22.8	34.0	38.1	0.47
	28	20	21.8	34.5	38.7	0.43
	37	18	20.4	32.0	38.3	0.73
	49	18	19.8	26.0	39.1	2.54

FF= Fast Female; FM= Fast Male; SF= Slow Female; SM= Slow Male; CF= Control Female; CM= Control Male

(.....continued)

Table 9.1. (continued)

Line/ Sex	Age	Temperature				Thermal Resistance of Feathers
		Surrounding	Ambient	Feather Surface	Back Skin	(r_f)
	(Days)	°C	°C	°C	°C	s/cm
CF2	10	22	24.0	33.5	39.2	0.75
	18	20	25.7	33.5	39.2	0.72
	22	21	22.8	33.0	39.0	0.76
	28	20	21.8	33.0	38.9	0.67
	37	18	20.4	27.0	39.2	2.20
	49	18	19.8	25.5	39.2	2.88
CM2	10	22	24.0	33.0	39.1	0.85
	18	20	25.7	33.5	39.1	0.71
	22	21	22.8	33.5	38.3	0.58
	28	20	21.8	34.0	38.8	0.52
	37	18	20.4	34.5	38.0	0.32
	49	18	19.8	25.0	39.1	3.17
SED		-	-	1.50	0.23	0.48
MAIN EFFECTS						
Age -	10	-	-	33.5	39.2	0.76
	18	-	-	33.8	39.2	0.67
	22	-	-	32.4	38.6	0.91
	28	-	-	31.8	38.8	1.11
	37	-	-	29.1	38.7	1.78
	49	-	-	25.9	39.0	3.13
SED		-	-	0.53	0.08	0.17
Line -	Fast	-	-	29.0	39.1	2.12
	Slow	-	-	32.8	38.7	0.81
	Control 1	-	-	30.9	38.9	1.48
	Control 2	-	-	31.6	38.9	1.18
SED		-	-	0.43	0.07	0.14
Sex -	Male	-	-	31.8	38.8	1.16
	Female	-	-	30.3	39.1	1.63
SED		-	-	0.31	0.05	0.10
Significance of Differences:						
Age (A)		-	-	***	***	***
Line (L)		-	-	***	***	***
Sex (S)		-	-	***	***	***
A x L		-	-	***	NS	***
A x S		-	-	***	**	**
L x S		-	-	*	NS	**
A x L x S		-	-	NS	NS	NS

NS= Non Significant; * = P < 0.05; ** = P < 0.01; *** = P < 0.001
N Total = 96 birds

Table 9.2. Effects of age, line and sex on body composition

Line/ Sex	Age (Days)	Starved Live Body Weight (gram)	Defeathered Body Weight (gram)	Feathers Weight (gram)	Whole Carcass (without meat) Weight (gram)	Meat Weight (gram)	Abdominal Fat Weight (gram)
FF	10	151.0	144.5	2.6	83.0	35.9	-
	18	285.6	270.3	4.0	182.7	76.3	-
	22	428.4	404.4	10.8	261.1	114.6	6.3
	28	604.1	572.0	21.1	372.1	183.4	7.5
	37	1112.4	1036.2	39.6	682.7	341.5	24.2
	49	1841.8	1711.8	91.9	1095.0	611.9	50.5
FM	10	157.5	152.3	2.2	88.8	39.3	-
	18	298.5	284.5	2.9	201.6	75.5	-
	22	441.6	416.6	10.6	273.0	117.4	4.8
	28	647.5	618.7	17.3	403.8	206.9	10.6
	37	1155.9	1087.3	35.3	715.3	344.6	23.3
	49	2185.3	2046.9	93.6	1286.5	747.6	48.4
SF	10	130.1	127.2	1.7	75.0	36.2	-
	18	282.1	272.0	1.7	171.5	86.8	-
	22	359.9	352.7	3.1	235.2	116.0	3.9
	28	577.6	549.9	12.0	348.8	192.8	5.0
	37	1047.3	988.2	23.9	637.5	337.3	19.3
	49	1761.4	1648.2	61.3	1023.8	611.7	43.5
SM	10	133.0	130.6	0.5	74.8	36.8	-
	18	263.5	258.4	1.1	166.7	80.0	-
	22	381.6	376.1	1.8	249.4	116.2	3.9
	28	600.4	586.8	5.6	376.6	205.8	4.6
	37	1088.5	1049.3	18.4	673.9	370.9	13.6
	49	2033.2	1913.5	62.0	1183.7	717.9	43.2
CF1	10	142.1	135.7	2.4	79.9	35.5	-
	18	286.6	273.0	3.3	185.0	77.7	-
	22	386.5	363.0	10.4	235.8	104.3	5.1
	28	606.5	571.1	17.0	371.9	191.4	8.5
	37	1050.5	976.0	37.0	639.3	329.6	20.6
	49	1775.3	1644.7	86.1	1067.3	568.6	39.9
CM1	10	135.0	131.2	0.9	77.9	35.8	-
	18	320.5	314.9	1.1	213.6	95.5	-
	22	425.6	411.2	4.1	264.4	120.7	5.4
	28	605.2	587.3	9.9	393.0	194.8	7.9
	37	1105.8	1049.1	29.2	671.5	364.4	16.8
	49	2051.6	1930.9	88.3	1228.1	693.7	44.3

FF= Fast Female; FM= Fast Male; SF= Slow Female; SM= Slow Male;
CF= Control Female; CM= Control Male

(.....continued)

Table 9.2. (continued)

Line/ Sex	Age (Days)	Starved Live Body Weight (gram)	Defeathered Body Weight (gram)	Feathers Weight (gram)	Whole Carcass (without meat) Weight (gram)	Meat Weight (gram)	Abdominal Fat Weight (gram)
CF2	10	140.1	136.2	1.9	78.4	34.1	-
	18	280.1	271.8	2.7	171.9	91.2	-
	22	429.6	415.0	4.3	269.0	122.3	5.1
	28	613.0	591.7	9.8	377.0	190.1	8.7
	37	1053.2	989.2	32.8	626.3	350.1	23.7
	49	1661.0	1549.4	70.9	923.5	613.0	37.6
CM2	10	137.5	134.9	1.2	76.3	34.0	-
	18	294.5	283.6	2.7	188.8	87.7	-
	22	370.5	358.8	4.7	231.2	110.3	4.4
	28	626.4	609.5	10.3	396.8	203.9	9.8
	37	1171.3	1120.5	19.0	726.8	385.5	23.5
	49	1986.0	1878.8	69.0	1167.1	701.8	50.1
SED		44.34	41.59	5.94	29.89	31.58	5.18
MAIN EFFECTS							
Age -	10	140.8	136.6	1.7	79.3	35.9	0.0
	18	288.9	278.6	2.4	185.2	83.8	0.0
	22	403.0	387.2	6.2	252.4	115.2	4.9
	28	610.1	585.9	12.9	380.0	196.1	7.8
	37	1098.1	1037.0	29.4	671.6	353.0	20.6
	49	1912.0	1790.5	77.8	1121.9	658.3	44.7
SED		15.68	14.71	2.10	10.57	11.16	1.83
Line -	Fast	775.8	728.8	27.6	470.4	341.2	14.6
	Slow	721.5	687.8	16.1	434.8	242.4	11.4
	Control 1	740.9	699.0	24.1	452.3	234.3	12.4
	Control 2	730.3	695.0	19.1	436.1	243.7	13.6
SED		12.80	12.01	1.71	8.63	9.11	1.49
Sex -	Male	775.7	738.8	20.5	472.1	253.6	13.1
	Female	708.6	666.4	23.0	424.7	227.2	12.9
SED		9.05	8.49	1.21	6.10	6.45	1.06
Significance of Differences:							
Age (A)		***	***	***	***	***	***
Line (L)		***	**	***	**	NS	NS
Sex (S)		***	***	*	***	***	NS
A x L		*	NS	**	**	NS	NS
A x S		***	***	NS	***	***	NS
L x S		NS	NS	NS	NS	NS	NS
A x L x S		NS	NS	NS	NS	NS	NS

NS = Non Significant; * = P < 0.05; ** = P <0.01; *** = P < 0.001; N Total= 96 birds

had higher live body weights than the control and slow feathering birds in both sexes. The amount of feathers was found to be more in the fast feathering line than those in control and slow feathering lines. The effects of age, line and sex on feather weight as per cent of live body weight are presented in Fig. 9.1. This figure shows that at 22 days of age the percentage of feather weight in the fast feathering line was obviously higher compared with those in the slow feathering line.

From the data of body weight (Table 9.2) and primary, secondary, tail and back feather lengths of 96 birds (Table 9.3.), a prediction equation for feather weight was calculated by multiple regression. The equation obtained was as follows:

$$Y = -2.24 - 0.432X_1 + 0.398X_2 + 0.187X_3 - 0.093X_4 + 0.0386X_5$$
$$SE: (\pm 2.17) \quad (\pm 0.07) \quad (\pm 0.08) \quad (\pm 0.05) \quad (\pm 0.15) \quad (\pm 0.002)$$

with the coefficient of determination (R^2) = 95.6%

where Y = predicted feather weight (gram)

X_1 = primary feather length (mm)

X_2 = secondary feather length (mm)

X_3 = tail feather length (mm)

X_4 = back feather length (mm)

X_5 = live body weight (gram)

There were no significant differences in meat yield between fast, control and slow feathering lines. However, when the meat weight was calculated as percentage of live body weight it showed that the slow feathering line had more of meat than the fast feathering line (Fig. 9.2). As

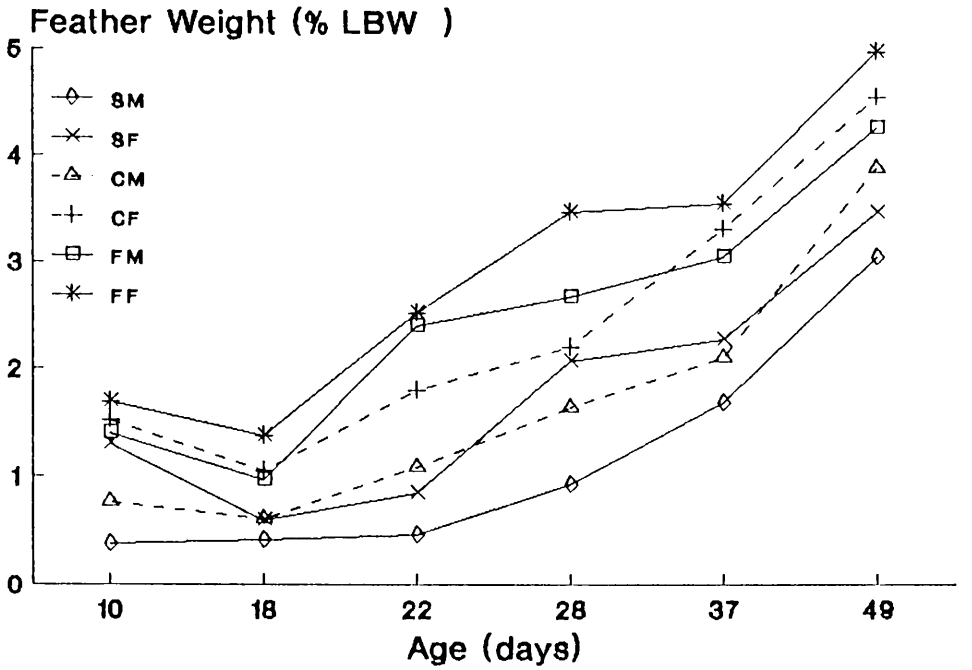


Figure 9.1. Effects of age, line and sex on feather weight as per cent of live body weight

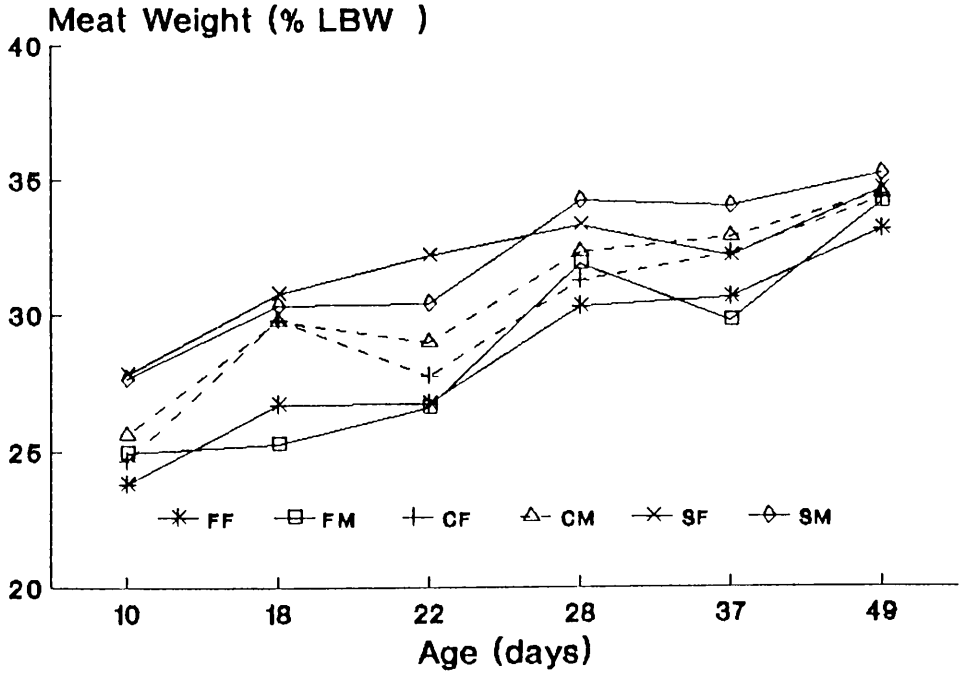


Figure 9.2. Effects of age, line and sex on meat weight as per cent of live body weight

Table 9.3. Effects of age, line and sex on feather lengths and back feather score

Line/ Sex	Age (Days)	Primary Feather Length (mm)	Secondary Feather Length (mm)	Tail Feather Length (mm)	Back Feather Length (mm)	Back Feather Score
FF	10	46.5	28.0	8.5	0.0	1.0
	18	77.0	55.0	17.0	8.0	2.0
	22	84.0	70.5	34.0	16.5	4.0
	28	104.5	93.5	58.5	23.0	5.5
	37	124.0	122.5	101.5	44.0	6.0
	49	144.0	137.5	133.0	48.5	6.0
FM	10	46.5	30.0	8.5	0.0	1.0
	18	71.5	53.0	17.0	7.5	2.0
	22	84.5	65.0	20.5	12.0	3.0
	28	107.5	93.0	30.0	19.5	4.5
	37	129.5	120.5	70.5	39.5	5.5
	49	142.5	144.0	117.5	44.5	6.0
SF	10	27.0	21.5	0.0	0.0	1.0
	18	38.0	21.5	7.5	2.5	1.5
	22	42.0	33.0	7.5	6.5	1.5
	28	82.0	63.5	23.5	11.0	3.0
	37	110.5	85.0	46.0	27.5	5.0
	49	122.5	87.5	43.5	33.5	4.5
SM	10	21.5	11.0	0.0	0.0	1.0
	18	30.0	18.5	7.5	0.0	1.0
	22	44.0	25.0	4.5	2.0	1.0
	28	67.5	36.5	13.0	5.0	2.0
	37	91.5	46.5	20.0	16.5	2.5
	49	132.5	108.5	45.0	42.5	4.0
CF1	10	44.0	28.5	7.5	0.0	1.0
	18	64.0	46.0	13.5	8.0	2.0
	22	87.0	68.0	29.0	14.0	3.5
	28	98.0	85.0	37.0	22.5	5.5
	37	121.5	117.0	81.5	42.5	6.0
	49	136.0	139.0	111.5	52.5	6.0
CM1	10	24.5	18.0	0.0	0.0	1.0
	18	33.0	18.5	6.5	0.0	1.0
	22	60.0	46.0	9.5	0.0	1.0
	28	83.0	54.5	21.0	6.0	2.0
	37	118.5	90.5	35.0	22.0	3.5
	49	142.0	140.0	71.0	46.5	5.0

FF= Fast Female; FM= Fast Male; SF= Slow Female; SM= Slow SM= Slow Male; CF= Control Female; CM= Control Male

(.....continued)

Table 9.3. (continued)

Line/ Sex	Age (Days)	Primary Feather Length (mm)	Secondary Feather Length (mm)	Tail Feather Length (mm)	Back Feather Length (mm)	Back Feather Score
CF2	10	33.5	22.0	2.5	0.0	1.0
	18	67.5	47.0	12.0	4.0	1.5
	22	67.5	49.5	11.0	5.0	1.5
	28	77.5	57.5	21.0	9.0	3.0
	37	114.5	109.0	57.0	38.0	5.5
	49	140.5	125.0	61.0	41.5	5.5
CM2	10	22.5	15.0	2.5	0.0	1.0
	18	53.5	40.5	12.5	3.0	1.5
	22	59.5	38.0	13.0	4.0	1.5
	28	80.0	53.0	16.0	8.5	2.5
	37	105.0	65.5	19.0	18.0	3.0
	49	132.0	126.0	62.0	40.5	5.0
SED		10.01	13.75	13.59	4.72	0.55
MAIN EFFECTS						
Age -	10	33.3	21.8	3.7	0.0	1.0
	18	54.3	37.5	11.7	4.1	1.6
	22	66.1	49.4	16.1	7.5	2.1
	28	87.5	67.1	27.5	13.1	3.5
	37	114.4	94.6	53.8	31.0	4.6
	49	136.5	125.9	80.6	43.8	5.3
SED		3.54	4.86	4.81	1.67	0.19
Line -	Fast	96.8	84.4	51.4	21.9	3.9
	Slow	67.4	46.5	18.2	12.3	2.3
	Cont 1	84.3	70.9	35.3	17.8	3.1
	Cont 2	79.5	62.3	24.1	14.3	2.7
SED		2.89	3.97	3.92	1.36	0.16
Sex -	Male	78.4	60.7	25.9	14.1	2.6
	Female	85.6	71.4	38.5	19.1	3.5
SED		2.04	2.81	2.77	0.96	0.11
Significance of Differences:						
Age (A)		***	***	***	***	***
Line (L)		***	***	***	***	***
Sex (S)		**	***	***	***	***
A x L		NS	NS	**	*	**
A x S		NS	*	*	**	***
L x S		NS	NS	NS	**	***
A x L x S		NS	NS	NS	NS	NS

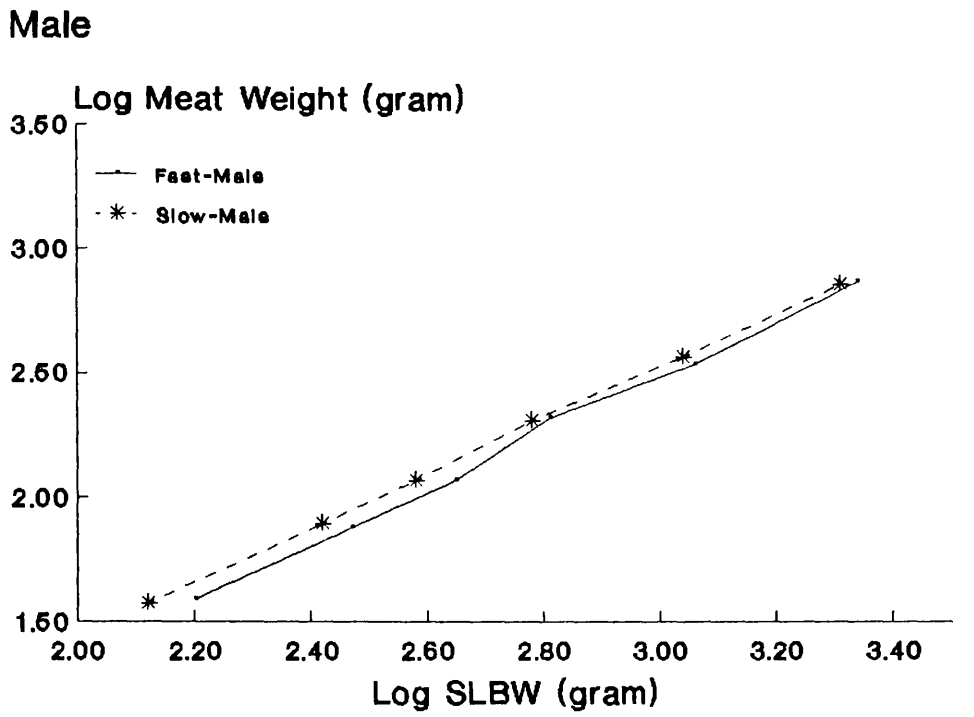
* = P < 0.05; ** = P < 0.01; *** = P < 0.001
NS= Non Significant; N Total= 96 birds

expected, the males had more meat than the females. Also, when the body weight and meat weight data were expressed on a log basis, and the resulting data plotted, graphs show clearly that the slow feathering line had more meat than the fast feathering line, in both sexes (Fig. 9.3). In the control lines no difference in meat weight between control 1 and 2 (Fig. 9.4) was found.

The defeathered weight minus meat weight was found to be greater in the fast feathering birds than those in the control and slow feathering birds in both sexes, and those in the male was greater than in the females. Age had an effect on abdominal fat. As the birds become older, they had more abdominal fat, but abdominal fat was not affected by line and sex.

IX.3.4. Dry Matter and Protein Content

Dry matter and protein content of feathers, meat and the whole carcass (without meat) were analysed (Table 9.4). There were no differences in the dry matter of feathers, meat and carcass (without meat) in both lines and sexes. The effect of age on feather, meat and carcass protein was similar in all lines and sexes. The crude protein content of feathers, meat and carcass showed a linear increase with age (example: Female; Fig. 9.5.). The protein in the carcass was higher than that in the meat and feathers.



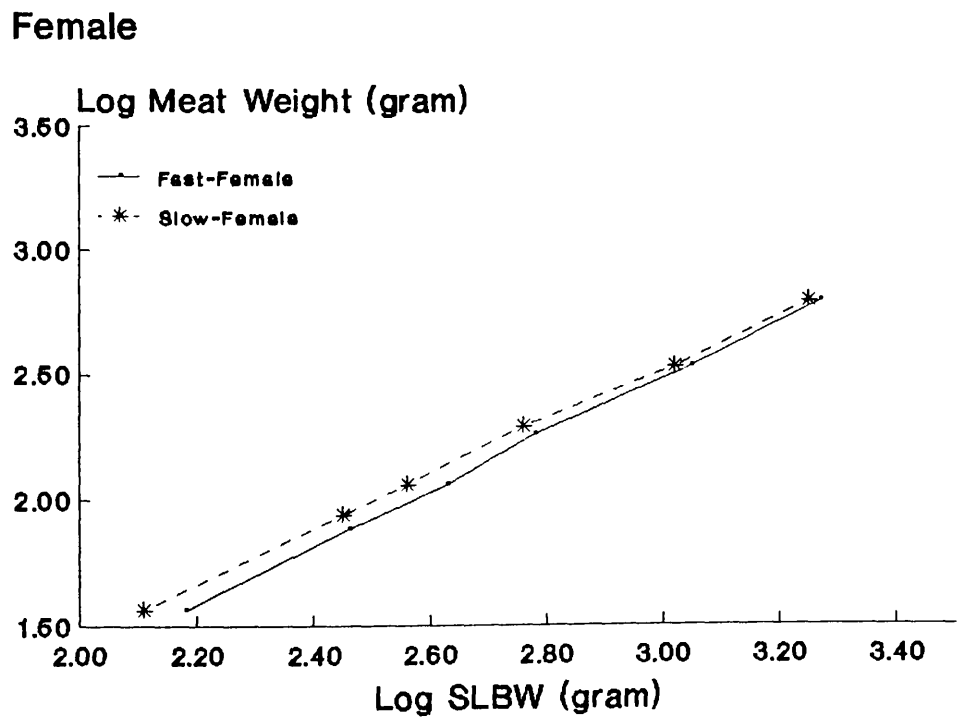
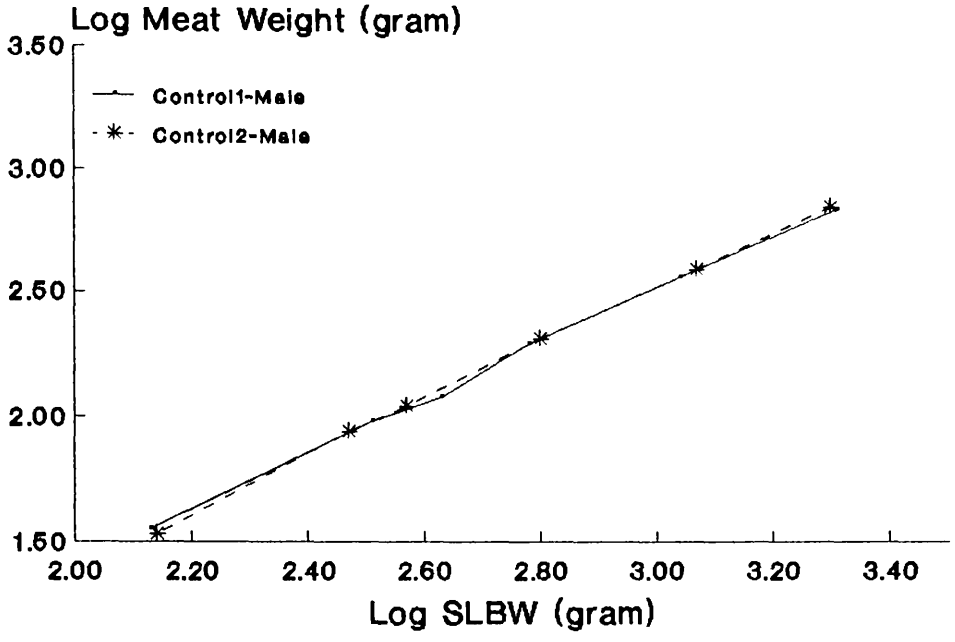


Figure 9.3. Effect of line on the relationship between meat and starved live body weight (SLBW)

Male



Female

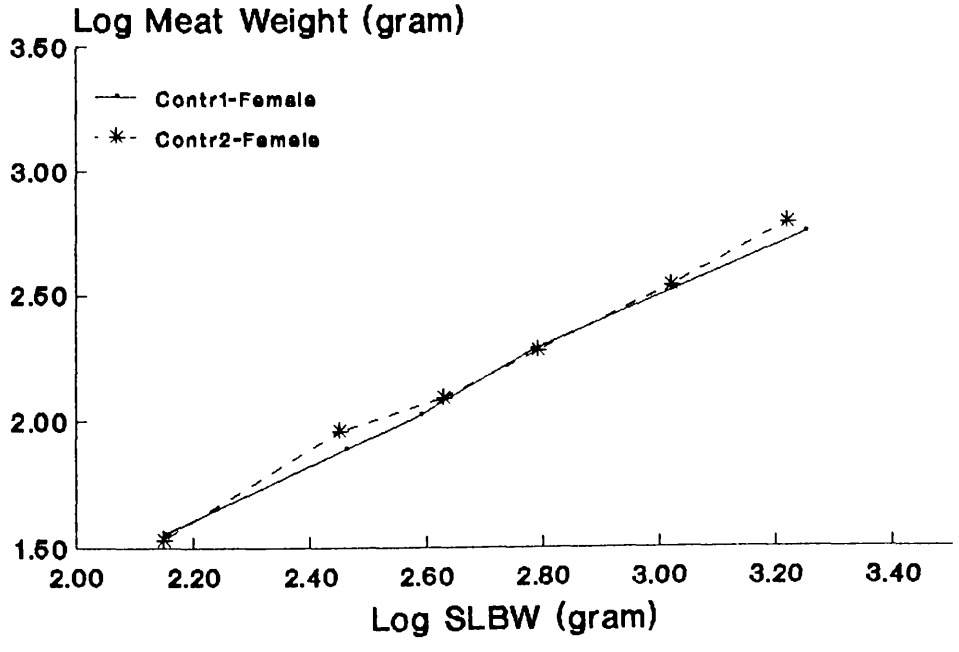


Figure 9.4. The relationship between meat and starved live body weight (SLBW) in the control lines

Table 9.4. Effects of age, line and sex on dry matter and protein content of meat, whole carcass (without meat) and feathers

Line/ Sex	Age	Meat		Whole Carcass without Meat		Feather	
	(Days)	Dry Matter g	C Protein g	Dry Matter g/kg	C Protein g	Dry Matter g/kg	C protein g
FF	10	251	6.4	300	14.4	899	2.1
	18	257	14.9	336	27.2	933	3.3
	22	249	23.2	359	42.4	930	9.0
	28	246	36.2	385	63.3	924	17.6
	37	247	67.7	453	106.2	927	33.9
	49	252	121.5	471	150.2	911	80.2
FM	10	245	6.6	298	14.1	910	1.9
	18	265	14.2	338	33.3	931	2.5
	22	248	23.6	342	44.4	928	8.9
	28	251	42.2	416	69.3	925	14.9
	37	248	67.7	442	118.0	925	30.0
	49	244	150.2	430	181.3	907	82.5
SF	10	248	6.7	324	14.0	904	1.4
	18	259	17.3	313	26.0	928	1.4
	22	259	24.4	358	43.3	934	2.4
	28	243	39.3	383	65.7	927	9.9
	37	255	68.8	430	104.1	930	20.6
	49	253	123.6	443	149.7	911	54.1
SM	10	255	6.4	310	13.2	892	0.4
	18	253	15.1	327	28.1	924	0.9
	22	244	23.1	343	45.1	932	1.5
	28	242	41.1	369	69.8	928	4.7
	37	249	75.8	455	129.2	927	15.7
	49	255	144.0	440	181.9	913	54.5
CF1	10	258	6.6	312	12.8	914	2.0
	18	255	15.1	351	27.8	935	2.7
	22	255	21.1	364	39.9	930	8.7
	28	255	38.6	391	58.2	925	14.6
	37	249	67.3	451	98.5	928	31.7
	49	250	109.2	448	150.0	911	75.3
CM1	10	245	6.6	313	13.8	891	0.8
	18	253	18.5	310	32.6	926	0.9
	22	254	23.2	353	44.8	933	3.3
	28	246	37.4	384	67.5	927	8.1
	37	244	72.3	431	110.1	930	25.5
	49	254	137.3	440	168.6	903	77.6

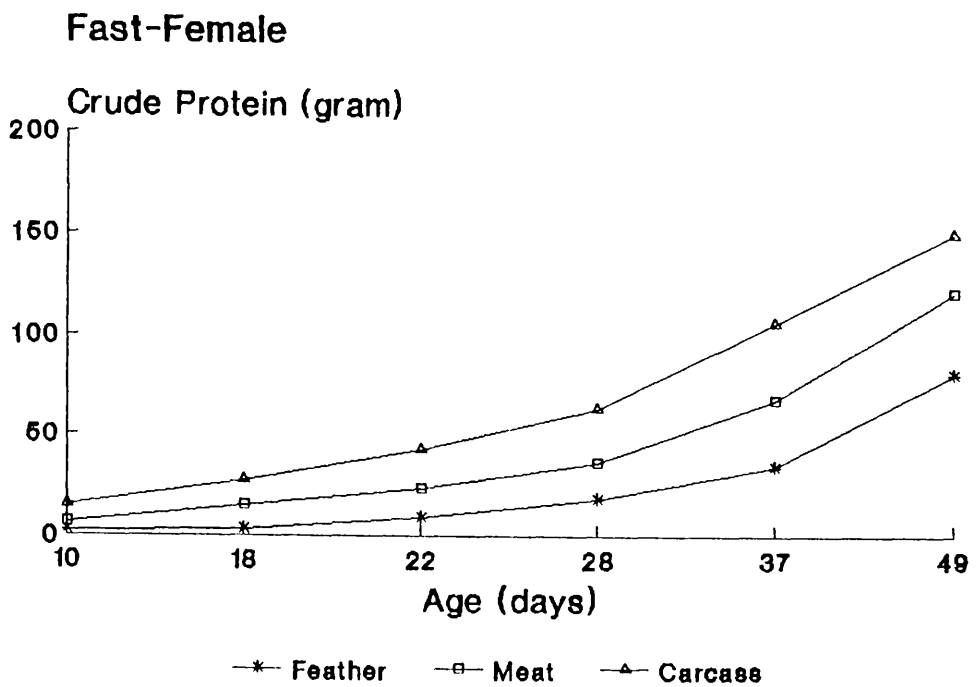
FF= Fast Female; FM= Fast Male; SF= Slow Female; SM= Slow Male;
CF= Control Female; CM= Control Male

(.....continued)

Table 9.4. (continued)

Line/ Sex	Age	Meat		Whole Carcass without Meat		Feather	
		Dry Matter	C Protein	Dry Matter	C Protein	Dry Matter	C protein
	(Days)	g	g	g/kg	g	g/kg	g
CF2	10	251	6.6	324	13.5	902	1.6
	18	252	17.0	327	26.8	933	2.3
	22	248	23.7	350	43.3	931	3.5
	28	254	36.0	390	65.1	927	8.2
	37	254	72.6	452	100.6	927	28.2
	49	251	123.1	430	132.6	909	62.6
CM2	10	247	5.8	304	12.4	900	1.0
	18	247	15.8	307	31.0	932	2.2
	22	260	22.1	344	40.0	935	3.9
	28	247	40.3	406	66.2	930	8.7
	37	244	77.5	424	121.8	929	16.0
	49	251	139.2	425	165.3	911	61.7
SED		7.26	5.9	17.03	6.8	7.74	5.21
MAIN EFFECTS							
Age -	10	249.8	6.4	310.3	13.5	901.2	1.4
	18	255.1	16.0	325.9	29.1	929.9	2.0
	22	251.8	23.1	351.4	42.9	931.4	5.2
	28	247.7	38.9	390.3	65.7	926.6	10.8
	37	248.4	71.2	442.2	111.1	927.6	25.2
	49	250.9	131.0	440.6	160.0	909.3	68.6
SED		2.57	2.10	6.02	2.42	2.74	1.84
Line -	Fast	250.1	47.9	380.5	72.0	920.7	23.9
	Slow	251.0	48.8	374.4	72.5	920.5	14.0
	Control 1	251.2	46.1	378.8	68.7	920.8	20.9
	Control 2	250.2	48.3	373.3	68.2	921.9	16.7
SED		2.10	1.71	4.92	1.97	2.23	1.50
Sex -	Male	249.4	50.2	372.6	75.1	920.1	17.8
	Female	251.9	45.3	380.9	65.7	921.8	19.9
SED		1.48	1.21	3.48	1.39	1.58	1.06
Significance of Differences:							
Age (A)		NS	***	***	***	***	***
Line (L)		NS	NS	NS	NS	NS	***
Sex (S)		NS	***	*	***	NS	NS
A x L		NS	NS	NS	NS	NS	**
A x S		NS	***	NS	***	NS	NS
L x S		NS	NS	NS	NS	NS	NS
A x L x S		NS	NS	NS	NS	NS	NS

NS = Non Significant; * = P < 0.05; ** = P < 0.01; *** = P < 0.001;
N Total = 96 birds



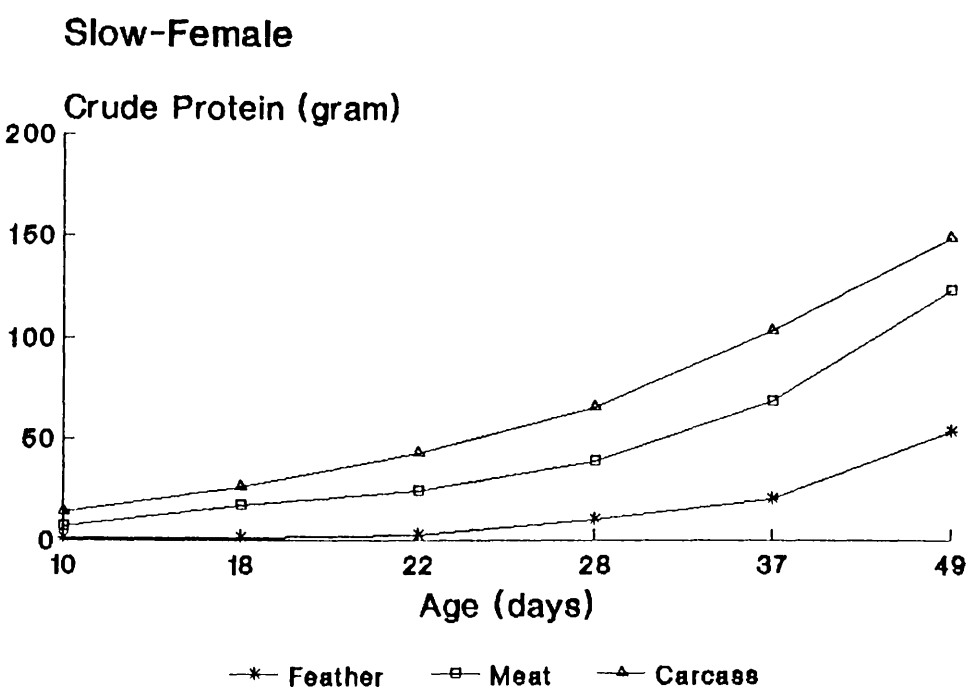


Figure 9.5. Effect of age on meat, carcass and feather protein in fast and slow feathering females

Generally, there was no effect of line on meat and carcass protein. However the fast feathering line had 10 g more protein in feathers than the slow feathering line. When the data are expressed as $\log_{10}$ the relationship between body weight, meat protein and feather + meat + carcass protein (for example: females) are presented in Figs. 9.6. and 9.7. These data show that the slow feathering line had more meat protein than the control and fast feathering lines, but there was no difference in feather + meat + carcass protein between the lines.

When the effect of line and sex on the feather + meat + carcass protein as percentage of total crude protein was illustrated at 22 and 49 days of age (Fig. 9.8), the fast feathering line is seen to have more protein in the feathers but the slow feathering line has more protein in the meat.

IX.4. DISCUSSION

A characterisation of the broiler as a function of sex, age, and breed has been reported by Moran and Orr (1969) and Moran *et al.* (1970). However, the influence of fast and slow feathering lines on their performance had not been evaluated in any detail because of a lack of genetically different lines for feather growth.

The control birds were used in this experiment were the progeny of the crossing fast-male x slow-female and slow-male x fast-female. Since the result was not different between control 1 and 2, therefore in this discussion the

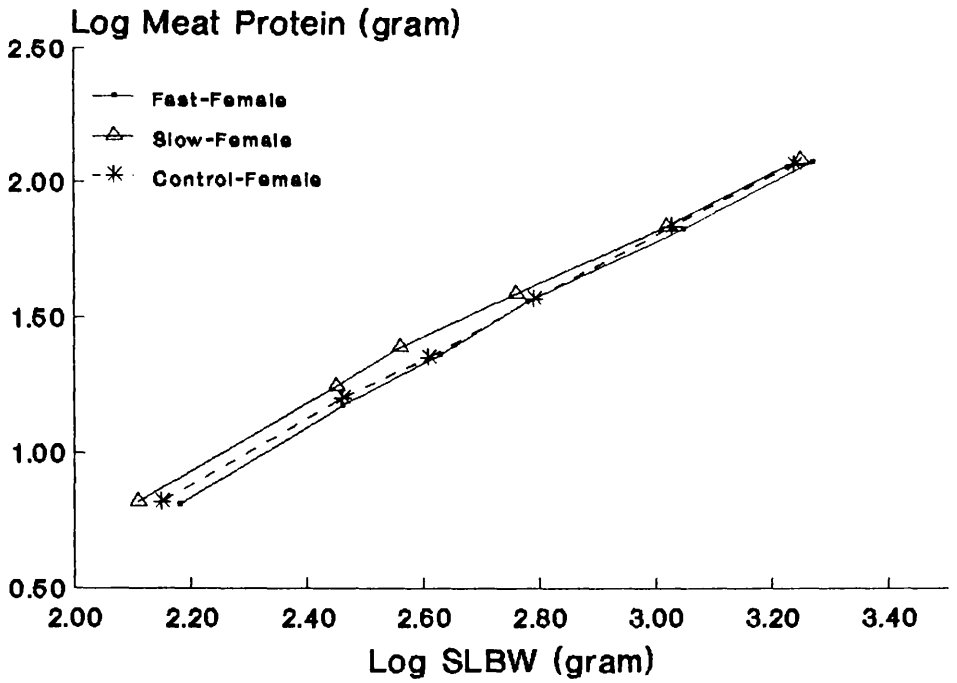


Figure 9.6. Effect of line on relationship between meat protein and starved live body weight (SLBW)

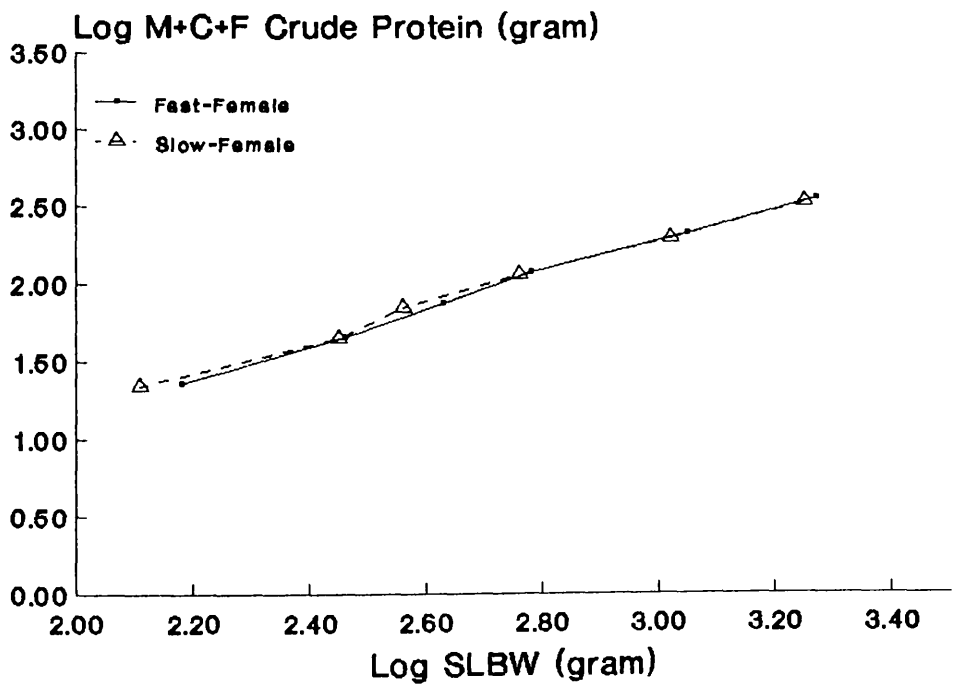
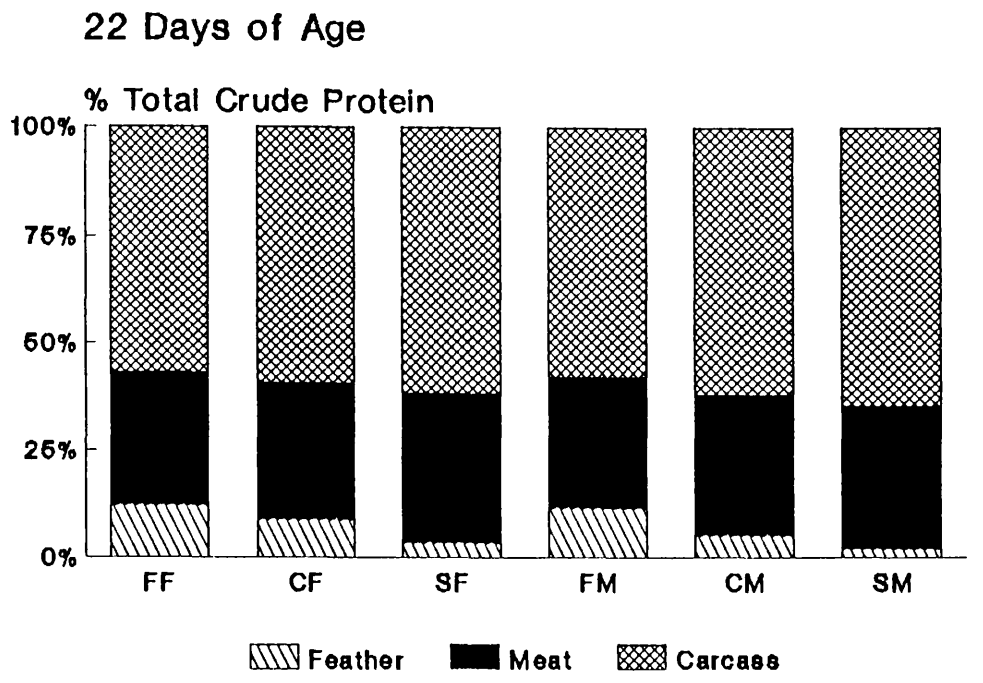


Figure 9.7. Effect of line on relationship between protein of meat, carcass and feathers and starved live body weight



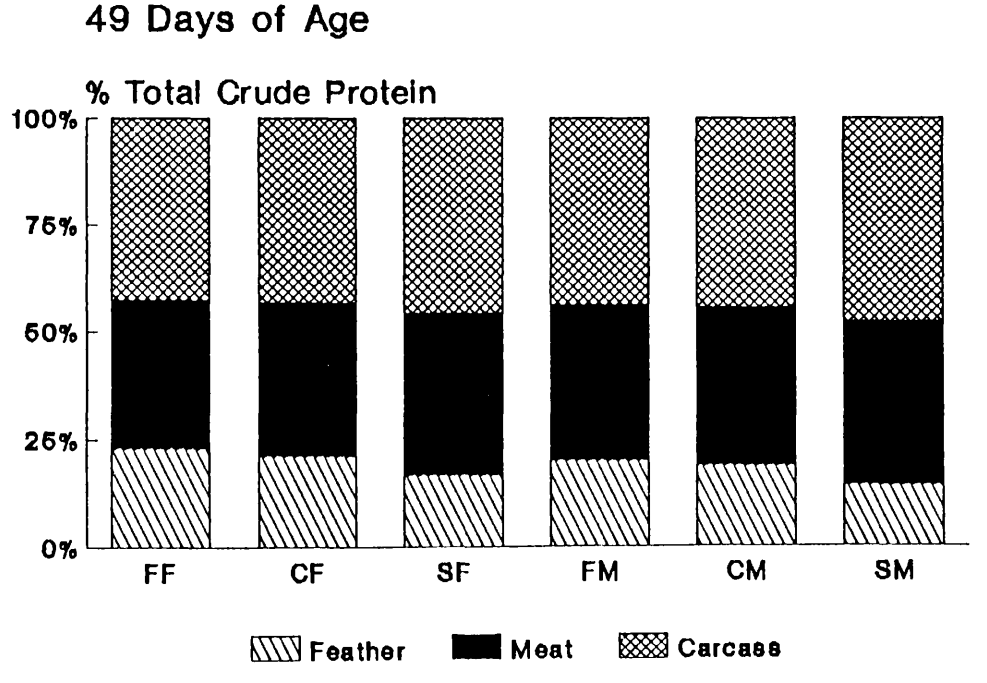


Figure 9.8. Effects of line and sex on meat, carcass and feather protein at 22 and 49 days of age. FF= Fast Female, CF= Control Female, SF= Slow Female, FM= Fast Male, CM= Control Male, SM= Slow Male

control line was taken as the result from the average of control 1 and 2. The effect of age, sex and line on skin and feather surface temperature, thermal resistance of the feathers and body composition will be discussed.

Growing animals are characterised by high rates of synthesis of tissue proteins. The changes in the rates of protein deposition are naturally reflected in the body composition of the animal. How much protein was found in the feathers and meat, are going to be discussed.

IX.4.1. Effect of Age

The skin and surface temperature were affected by age. The decrease of feather surface temperature ($0.2^{o}C/d$) with age appears to be associated with the increase in feather weight (2 g/d).

Increases in live body weight with age, are consequence of increases in feather weight, meat weight, carcass weight and abdominal weight. It was found that aging was associated with increases in the protein content of feathers, meat and carcass. This result is in agreement with Edwards *et al.* (1973) who reported that there is a very slight increase in the ash and protein content of the carcass with age. Fisher *et al.* (1981) reported that the crude protein content of feathers increased with age.

IX.4.2. Effect of Sex

Males had slightly higher surface temperatures than females (31.8^{o}C vs. 30.3^{o}C). The difference in skin temperature was very small (39.0^{o}C vs. 38.8^{o}C). The difference between these temperatures seems due to females having more feathers than males. Because of this, males had lower thermal resistance values than females (1.16 s/cm vs. 1.63 s/cm).

Generally females had more feathers [absolute feather weight or feather weight as percentage of body weight (3.3% vs. 2.6%)] and longer feathers than males.

Males had higher meat weights and the whole carcass (minus feathers and meat) weights than females. However, meat as percentage live body weight was not significantly different between males and females. Abdominal fat in females and males was also not different. Grey *et al.* (1982) reported that male broilers grew linearly up to 76 d whereas the females grew more slowly after 35 d Up to 56 d, males had a slightly higher eviscerated yield. There was no significant difference between the sexes beyond this age.

Meat and defeathered carcass protein was found to be higher in males than in females. This result is in agreement with Pym and Solvyns (1979) who reported that females had less protein and water than males. But in this study it was found that the meat and defeathered carcass protein as a percentage total body protein was not different between males and females. However, females had more feather protein than males as an absolute weight or as percentage of total

body protein (15.2% vs. 12.5%).

IX.4.3. Effect of Line

The slow feathering line had 0.3°C lower skin temperature but 3.8°C higher feather surface temperature than fast feathering line. The important of feathers in conserving heat can be explained from the results of thermal resistance. Since the slow feathering line had poor feather cover, they had 1.3 s/cm lower thermal resistance of feathers than the fast feathering line.

The fast line had a greater body weight than control and slow feathering lines. Feather weight as percentage of live body weight was higher in fast feathering line than in control and slow featheing lines (3.6% vs 2.9% and 2.2%, respectively). The whole carcass without meat as percentage of live body weight was higher in fast feathering line than in control and slow feathering lines (66.4% vs. 60.4% and 60.3%, respectively). However, no differences in meat and abdominal fat weight was observed between lines. These results are supported by several researches. Zein-el-Dein *et al.* (1984) reported that the depressing of the Na gene on plumage weight in proportion to live body weight gave an improvement of yield of the eviscerated carcass. Summers and Leeson (1979) and Becker *et al.* (1981) reported that they did not find any statistically significant differences in visceral and abdominal fat among tested strains. Furthermore, Zein-el-Dein *et al.* (1984) and El-Attar and

Merat (1985) who worked with Naked Neck birds found that abdominal fat does not differ according to genotype.

There were no differences in meat and carcass protein between lines. But the fast feathering line had more protein in feathers than the control and slow feathering lines (16.6% vs. 14.0% and 10.3%, respectively). However, the slow feathering line had about 3 per cent more meat and carcass protein as a percentage of the whole carcass protein than the fast feathering line. It is indicated from these results that the lower amount of feathers in the slow line will make more protein available for other tissues, in particular, meat.

CHAPTER X. EXPERIMENT 7:

ENERGY AND PROTEIN METABOLISM

X.1. INTRODUCTION

The most outstanding characteristic of all animals of the Aves class is the presence of feathers. There is considerable interest in the differences of feathering in the chickens when raised under commercial conditions because of its effect on thermal insulation and the likely consequences for energy utilisation and food intake. The feathers play a role in conserving heat and so have an influence on economic returns in production of poultry meat.

This experiment was conducted to study the influence of feathering on the heat production and efficiency of utilisation of metabolisable energy by the slow and fast lines of broiler chickens. Since this study was more specific on differences of feathering between lines, therefore it was decided to express heat production on the basis of surface area.

To determine whether differences in feathering existed in broilers due to rearing in a different environment to that in the preceding study, feather weight and feather lengths were recorded again. The effect of age, line and sex on rectal, skin and feather surface temperature, and, thermal resistance of the feathers was also studied.

X.2. MATERIALS AND METHODS

X.2.1. Experimental Design

In this study, three lines (fast, control and slow) and two sexes were involved, but only five calorimeter chambers were available. Therefore the experiment was performed as a balanced incomplete randomised block design. In this case, the assumption is made that age is replicated in some sense, and treatments (sex/line) do not interact with age.

X.2.2. Birds and Management

Two hundred and forty day-old females and males from the fourth generation of fast, control and slow feathering lines were hatched on 5th February 1990. At hatching day, the chicks were wing banded according to lines and they were put in a battery brooder overnight. The following day, the chicks were vent-sexed and transported to the Institute of Animal Physiology and Genetics Research, Roslin. They were reared to ten days old in a battery brooder in a brooding room. Then they were randomly allocated (in pairs) to cages in a climate room controlled at 24^{o}C. The floor dimension of the cage was 0.36 x 0.42 m. The lighting pattern was 23 h light : 1 h dark. They were fed on broiler starter and grower diets.

X.2.3. Recording Procedures

Skin and feather surface temperature and feather weight of the birds were recorded after the heat production of each pair of birds was measured during a three day period in the calorimeter chamber. On the following day, the skin and surface temperature of the birds in the climate room were also recorded as a control.

a. Body, Skin and Surface Temperature

The usual measure of deep body temperature in birds is rectal temperature. The rectal (20mm insertion) temperature was measured by a digital thermometer. The equipment for measuring skin, surface temperature, ambient and surrounding temperature were the same as used in experiment 6 (see materials and methods).

b. Thermal Resistance of the Feathers

The formula for calculation of thermal resistance of the feathers (r_f) was the same as used in experiment 6.

c. Heat Production Measurements

The heat production of birds was determined using the automated indirect calorimetry system described by Lundy *et al.* (1978) with improvements to the gas analysis system (MacLeod *et al.*, 1985). Two birds from the same line and sex were placed in each calorimeter chamber at a dry bulb air temperature of 22^{o}C and a relative humidity of 70 per cent

(PH_2O = 1.7 kPa). The lighting pattern was synchronous in the climate room and the calorimeter. The heat production of each pair of birds was measured for 24 hours during each of three days in the calorimeter chambers.

Measurements of oxygen consumption and carbon dioxide production were made over periods of about 22 hours, the remaining 2 hours of the 24 being required for the collection of excreta and refeeding the bird. All the respiratory exchange measurements were extrapolated to a 24 hours basis.

No correction was applied for nitrogen excretion since Romijn and Lokhorst (1961, 1966) pointed out that the error resulting from this omission is typically about 0.2 per cent and should not exceed 1.5 per cent even at a high rate of protein catabolism.

The heat production (H) was expressed on the total body surface area basis (W/m^2). The total body surface area was estimated from the body weight (M) using Meeh's formula (as cited by Leighton *et al.*, 1966; Tullets *et al.*, 1980):

$$S = k \times M^{0.67}$$

where S = surface area (cm^2)

k = constant = 10

M = body weight (grams)

d. Metabolisable Energy and Nitrogen Intake

d.1. Feed and Water Intake

Feed and water intakes were measured daily during the period spent in the calorimeter chamber.

d.2. Dropping Collection and Storage

Total collection procedures were used. Daily droppings collection were bulked to give a three-day sample. The droppings were collected in polymethacrylate (Perspex) trays placed on the floors of the calorimetric chambers. The samples were stored at -20°C in sealed plastic cups until they were freeze-dried and ground for analysis. Apparent metabolisable energy (AME) was calculated as:

$$I_{AME} = I_E - (F_E + U_E)$$

and apparent metabolisability as: I_{AME}/I_E

Total energy retention was calculated as:

$$R_E = I_E - (F_E + U_E) - H$$

Nitrogen retention was calculated as:

$$R_N = I_N - (F_N + U_N)$$

Crude protein retention was calculated as: $R_{XP} = 6.25\ R_N$

Energy retained as crude protein was calculated as:

$R_{E,XP} = 23.7\ R_{XP}$

The value of 23.7 kJ/g was used for the energy contents of protein (Znaniecka, 1967).

Energy retained as fat was calculated as:

$$R_{E,XL} = R_E - R_{E,XP}$$

Where symbols **I**= rate of intake (g/d), **R**= rate of retention (g/d), **H**= heat production rate (kJ/d), **F**= rate of faeces production (g/d), **U**= rate of urine production (g/d), and subscripts **E**= energy (heat of combustion, kJ/d), **N**= mass of nitrogen (g/d), **XP**= crude protein g/d, **XL**= crude lipid (ether extract, g/d).

All the calculations above were described by MacLeod *et al*. (1988).

d.3. Chemical Analysis of Feed and Droppings

Energy contents of excreta and feed samples were measured in an adiabatic bomb calorimeter (Gallenkamp). Nitrogen contents were measured by the Kjeldahl method, using Buchi digestion and distillation.

e. Feather and Defeathered Body Weight

After three days in the calorimeter, the birds were individually weighed and killed by injecting 20ml Sagatal (Anaesthesia) in the vein of the wing. Feathers from individual birds were removed by hand-dry plucking and put in the weighed plastic bag. Feathers and defeathered body weight were recorded.

X.3. RESULTS

X.3.1. Rectal, Skin and Feather Surface Temperature

The results of the rectal, skin and feather surface temperature of the birds from the calorimeter are presented in Table 10.1, and those temperatures of the birds in the climate room can be seen in Appendix 14.

The skin and surface temperature were affected by age, line and sex. The fast feathering line had higher skin temperature than the slow feathering line, but the feather surface temperature was opposite. The rectal temperature was affected by age and line. The fast feathering line had slightly higher rectal temperature than those in the slow line. The rectal temperature was not significantly different between sexes.

X.3.2. Thermal Resistance of the Feathers

The thermal resistance of the feathers of the birds in the calorimeter and in the climate room were affected by age, line and sex (Table 10.1 and Appendix 14). When the birds become older, a higher thermal resistance of the feathers was found.

The fast feathering line had higher thermal resistance than slow feathering line. For example, at 26 days of age the difference in thermal resistance of feathers between fast and slow lines in the calorimeter was approximately 2.0 s/cm. In general, females had higher thermal resistance of

Table 10.1. Effects of age, line and sex on physiological variables

Line/ Sex	Age	Temperature					Thermal Resistance of Feathers
		Rectal	Back Skin	Feather Surface	Surrounding	Ambient	
	(Days)	°C	°C	°C	°C	°C	(r_f) s/cm
FF	16	41.0	39.3	31.8	19.0	21.4	0.90
	19	41.3	39.1	31.0	18.0	20.5	0.95
	26	41.1	39.2	25.8	18.0	20.5	2.78
	30	41.3	39.6	25.5	18.3	20.6	3.17
	33	-	-	-	18.3	20.4	-
	37	41.2	39.7	24.2	18.7	21.0	4.76
	40	41.3	39.4	24.0	19.0	21.5	5.40
	44	41.3	39.5	23.7	19.0	21.2	5.81
FM	16	41.0	39.2	31.5	19.0	21.4	0.94
	19	41.1	39.3	32.0	18.0	20.5	0.79
	26	40.4	39.3	27.2	18.0	20.5	2.08
	30	-	-	-	18.3	20.6	-
	33	41.3	39.8	26.3	18.3	20.4	2.66
	37	41.1	39.7	24.3	18.7	21.0	4.63
	40	41.6	39.8	25.3	19.0	21.5	3.85
	44	41.5	39.7	24.3	19.0	21.2	4.90
SF	16	40.8	38.2	31.8	19.0	21.4	0.76
	19	41.2	38.3	33.5	18.0	20.5	0.47
	26	40.9	38.2	33.2	18.0	20.5	0.50
	30	41.1	38.5	31.8	18.3	20.6	0.75
	33	41.4	39.0	34.0	18.3	20.4	0.48
	37	-	-	-	18.7	21.0	-
	40	41.4	39.3	24.5	19.0	21.5	4.62
	44	41.3	39.3	24.7	19.0	21.2	4.26
SM	16	41.0	38.4	31.3	19.0	21.4	0.88
	19	41.2	38.4	33.0	18.0	20.5	0.55
	26	-	-	-	18.0	20.5	-
	30	41.0	38.7	34.7	18.3	20.6	0.37
	33	41.2	39.0	33.7	18.3	20.4	0.52
	37	41.0	38.9	35.0	18.7	21.0	0.36
	40	41.2	39.1	29.7	19.0	21.5	1.37
	44	41.2	39.3	26.7	19.0	21.2	2.61
CF	16	41.0	38.8	31.8	19.0	21.4	0.84
	19	-	-	-	18.0	20.5	-
	26	41.1	39.2	27.8	18.0	20.5	1.83
	30	41.4	39.4	26.2	18.3	20.6	2.67
	33	41.4	39.5	26.3	18.3	20.4	2.60
	37	41.1	39.5	24.7	18.7	21.0	4.10
	40	41.5	39.4	24.7	19.0	21.5	4.40
	44	-	-	-	19.0	21.2	-

FF= Fast Female; FM= Fast male; SF=Slow Female; SM= Slow Male;
CF= Control Female

(.....continued)

Table 10.1. (continued)

Line/ Sex	Age (Days)	Temperature Rectal °C	Back Skin °C	Feather Surface °C	Surrounding °C	Ambient °C	Thermal Resistance of Feathers (r_f) s/cm
CM	16	-	-	-	19.0	21.4	-
	19	41.4	39.2	32.3	18.0	20.5	0.73
	26	40.9	39.5	28.7	18.0	20.5	1.57
	30	41.5	39.6	28.8	18.3	20.6	1.59
	33	41.3	39.9	28.0	18.3	20.4	1.90
	37	41.2	39.8	24.8	18.7	21.0	4.08
	40	-	-	-	19.0	21.5	-
	44	41.5	39.7	25.2	19.0	21.2	3.84
SED		0.10	0.10	1.20	-	-	0.48
MAIN EFFECTS							
Age -	16	41.0	38.8	31.6	-	-	0.86
	19	41.2	38.9	32.4	-	-	0.70
	26	40.9	39.1	28.5	-	-	1.92
	30	41.3	39.2	29.4	-	-	1.71
	33	41.3	39.4	29.7	-	-	1.63
	37	41.1	39.5	26.6	-	-	3.59
	40	41.4	39.4	25.6	-	-	3.93
	44	41.4	39.5	24.9	-	-	4.28
SED		0.09	0.10	1.18	-	-	0.47
Line -	Fast	41.2	39.5	26.9	-	-	3.12
	Slow	41.1	38.8	31.3	-	-	1.32
	Control	41.3	39.5	27.4	-	-	2.51
SED		0.07	0.07	0.85	-	-	0.34
Sex -	Male	41.2	39.3	29.1	-	-	2.01
	Female	41.2	39.1	28.1	-	-	2.60
SED		0.06	0.06	0.70	-	-	0.28
Significant of Differences:							
Age (A)		***	***	***	-	-	***
Line (L)		*	***	***	-	-	***
Sex (S)		NS	NS	*	-	-	*
L x S		NS	NS	NS	-	-	NS

NS = Non Significant; * = P < 0.05; ** = P < 0.01; *** = P < 0.001
CM= Control Male

the feathers than males.

X.2.3. Live Body Weight, Feather Weight and Feather Length

Live body weight, defeathered body weight and feather weight were affected by age, line and sex (Table 10.2. and Appendix 15). Fast feathering birds had higher live body weights than control and slow feathering birds in both sexes. The amount of feathers was found to be more in the fast feathering line than those in control and slow feathering lines.

From the data of body weight and primary, secondary, tail and back feather lengths of 80 birds (Table 10.2), the feather weight can be predicted from the multiple regression equation as follows:

$$Y = -13.4 - 0.068X_1 + 0.160X_2 + 0.157X_3 + 0.660X_4 + 0.0298X_5$$
$$SE: (\pm 4.53)\ (\pm 0.11)\ (\pm 0.14)\ (\pm 0.07)\ (\pm 0.33)\ (\pm 0.006)$$

with the coefficient of determination (R^2) = 97.3%

where Y = predicted feather weight (gram)

X_1 = primary feather length (mm)

X_2 = secondary feather length (mm)

X_3 = tail feather length (mm)

X_4 = back feather length (mm)

X_5 = live body weight (gram)

Table 10.2. Effects of age, line and sex on live body weight, defeathered body weight, feather weight, feather length and back feather score

Line/ Sex	Age (day)	Live Body Weight (gram)	Defeathered Body Weight (gram)	Feather Weight (gram)	Primary Feather Length (mm)	Secondary Feather Length (mm)	Tail Feather Length (mm)	Back Feather Length (mm)	Back Feather Score
FF	16	375.0	353.9	18.3	84.5	70.0	33.5	13.0	3
	19	464.0	441.0	23.0	92.5	81.0	50.5	20.0	4
	26	782.5	725.9	52.0	108.0	102.0	75.5	32.5	6
	30	958.5	895.8	59.0	115.0	109.5	83.5	37.5	6
	33	-	-	-	-	-	-	-	-
	37	1215.0	1128.7	74.9	127.0	126.0	99.5	47.0	6
	40	1342.5	1241.8	79.1	117.5	125.5	114.5	48.5	6
	44	1545.0	1420.1	102.2	137.5	130.5	121.0	48.0	6
FM	16	421.5	404.5	14.6	82.0	66.5	27.5	10.0	2
	19	516.0	488.2	23.4	86.0	68.0	36.0	14.0	3
	26	821.0	778.4	38.2	107.5	91.0	39.5	26.0	5
	30	-	-	-	-	-	-	-	-
	33	1222.5	1153.7	65.0	127.0	114.5	81.0	41.0	6
	37	1455.0	1352.9	87.9	133.5	126.5	96.5	46.0	6
	40	1497.5	1395.5	88.6	134.0	131.0	86.5	48.0	6
	44	1835.0	1707.0	108.0	143.0	138.5	102.5	51.5	6
SF	16	370.0	366.9	2.5	35.0	19.5	2.5	0.0	1
	19	410.0	411.0	2.0	29.0	19.0	4.5	2.5	1
	26	650.5	635.0	14.5	64.5	32.0	16.0	8.0	2
	30	844.0	810.8	27.7	59.5	33.0	21.5	13.5	3
	33	980.0	941.8	35.0	78.5	33.5	17.5	15.0	3
	37	-	-	-	-	-	-	-	-
	40	1295.0	1200.6	77.0	120.5	115.0	66.0	44.0	6
	44	1517.5	1409.1	87.2	126.5	121.0	61.0	48.5	6
SM	16	345.0	343.6	1.5	38.0	16.0	4.5	0.0	1
	19	485.5	483.8	1.9	35.5	13.0	1.5	1.5	1
	26	-	-	-	-	-	-	-	-
	30	855.5	839.5	13.9	42.0	28.0	10.0	4.5	2
	33	1056.5	1025.6	26.3	85.0	41.5	19.5	11.5	3
	37	1231.0	1176.6	44.0	104.0	65.5	18.5	20.0	3
	40	1517.0	1431.8	64.0	76.0	76.0	22.5	32.0	5
	44	1745.0	1647.8	78.1	98.5	81.5	39.0	41.0	6
CF	16	342.5	331.5	8.7	72.0	51.0	17.0	5.0	1
	19	-	-	-	-	-	-	-	-
	26	675.0	631.4	38.6	105.5	89.0	41.0	25.5	5
	30	951.0	880.9	62.4	116.5	106.0	71.5	36.0	6
	33	1034.0	958.5	61.9	120.0	114.0	70.5	36.0	6
	37	1212.5	1124.1	80.7	124.5	119.5	77.5	39.0	6
	40	1327.5	1235.3	81.5	133.5	129.0	78.0	44.0	6
	44	-	-	-	-	-	-	-	-

FF= Fast Female; FM= Fast Male; SF= Slow Female; SM= Slow Male; CF= Control Female

(.....continued)

Table 10.2. (continued)

Line/ Sex	Age (day)	Live Body Weight (gram)	Defeathered Body Weight (gram)	Feather Weight (gram)	Primary Feather Length (mm)	Secondary Feather Length (mm)	Tail Feather Length (mm)	Back Feather Length (mm)	Back Feather Score
CM	16	-	-	-	-	-	-	-	-
	19	473.0	457.8	10.7	83.5	56.5	16.0	8.0	2
	26	807.5	768.5	33.7	106.0	87.0	25.0	23.0	5
	30	1083.5	1023.9	50.8	115.0	96.0	35.0	25.5	5
	33	1107.5	1035.6	62.1	121.5	94.0	40.0	29.0	5
	37	1311.5	1225.8	72.2	131.0	122.5	57.5	45.0	6
	40	-	-	-	-	-	-	-	-
	44	1735.0	1622.4	95.8	141.0	141.5	70.0	50.5	6
SED		35.4	32.03	5.33	7.45	7.34	6.30	3.09	0.45
MAIN EFFECTS									
Age -	16	370.8	360.1	9.1	62.3	44.6	17.0	5.6	1.6
	19	469.7	456.4	12.2	65.3	47.5	21.7	9.2	2.2
	26	747.3	707.8	35.4	98.3	80.2	39.4	23.0	4.6
	30	938.5	890.2	42.8	89.6	74.5	44.3	23.4	4.4
	33	1080.1	1023.0	50.1	106.4	79.5	45.7	26.5	4.6
	37	1285.0	1201.6	68.4	124.0	112.0	69.9	39.4	5.4
	40	1395.9	1301.0	78.0	116.3	115.3	73.5	43.3	5.8
	44	1675.5	1561.3	94.3	129.3	122.6	78.7	47.9	6.0
SED		34.70	31.38	5.22	7.30	7.19	6.17	3.03	0.44
Line -	Fast	1032.2	963.4	59.6	113.9	105.8	74.8	34.5	5.1
	Slow	950.2	908.9	34.0	69.7	49.6	21.8	17.3	3.1
	Control	1005.0	941.3	54.9	114.2	100.5	49.9	30.5	4.9
SED		25.00	22.65	3.77	5.27	5.19	4.46	2.18	0.32
Sex -	Male	1076.1	1018.2	49.0	99.5	82.8	41.4	26.4	4.2
-	Female	914.6	857.2	49.4	98.4	86.3	56.1	28.2	4.5
SED		20.40	18.49	3.08	4.30	4.24	3.64	1.78	0.26
Significance of Differences:									
Age (A)		***	***	***	***	***	***	***	***
Line (L)		**	*	***	***	***	***	***	***
Sex (S)		***	***	NS	NS	NS	***	*	NS
L x S		NS	NS	NS	NS	NS	NS	NS	NS

NS = Non Significant; * = P < 0.05; ** = P < 0.01; *** = P < 0.001

CM = Control Male

X.2.4. Heat Production

The heat production of fast, control and slow feathering lines in both sexes was measured from 15 to 45 days of age (during 3-day periods). In the third run of the calorimeter experiment (22 days of age), the birds failed to consume adequate amounts of food in the chambers and data for these days were removed from statistical analysis.

Generally, the slow feathering line had higher heat production than control and fast feathering lines. There was no significant difference in heat production between sexes (Table 10.3.). The heat production at different ages was variable, probably due to different birds being used every 3-days period in the calorimeter.

Since the difference of feathering between fast and slow lines was obviously seen at about 19 days of age and the oldest birds were used in this experiment were 44 days of age, therefore it is better to see the feather weight at those ages (Fig. 10.1) and compare it with the heat production at 19 and 44 days of ages (Fig. 10.2). It shows that at 19 day of age, the fast feathering line had 3 grams more feather weight and 4.9 W/m^2 (male) or 12.7 W/m^2 (female) lower heat production than the slow feathering line. At 44 day of age, the fast feathering line had 30 grams (male) or 15 grams (female) more feather weight and 10.5 W/m^2 (male) or 7.4 W/m^2 (female) lower heat production than the slow feathering line.

Table 10.3. Effects of age, line and sex on heat production (W/m^2)

Age	Fast		Control		Slow	
(Days)	Male	Female	Male	Female	Male	Female
16	96.7	96.4	-	95.4	97.0	90.4
19	101.0	88.1	97.4	-	105.9	100.8
26	90.0	86.5	93.3	86.3	-	99.9
30	-	63.8	92.8	70.2	89.6	85.0
33	82.9	-	90.7	81.5	98.7	96.8
37	64.4	56.5	65.4	71.9	92.3	-
40	65.3	68.2	-	61.0	77.5	74.2
44	70.4	65.7	80.7	-	80.9	73.1

MAIN EFFECTS		Heat Production (W/m2)
Line	- Fast	78.3
	- Slow	90.2
	- Control	82.2
SED		2.47
Sex	- Male	86.6
	Female	80.6
SED		2.89
Age	- 16	95.2
	19	98.6
	26	91.2
	30	80.3
	33	90.1
	37	70.1
	40	69.2
	44	74.2
SED		3.55

Significance of Differences:

Age (A) = *** Line (L) = *** Sex (S) = NS L x S = NS

*** = P < 0.001; NS = Non Significant

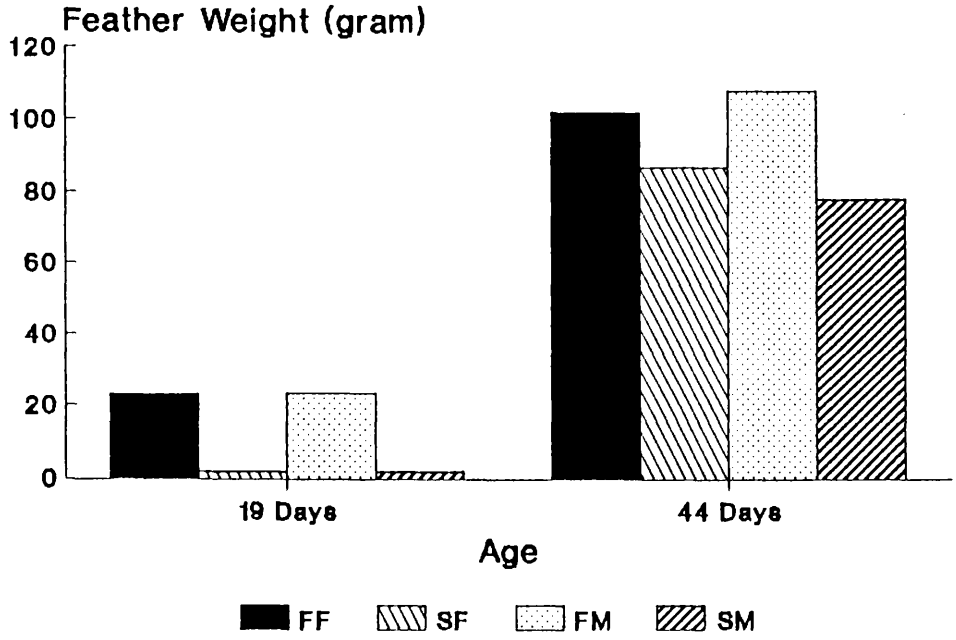


Figure 10.1. Effects of line and sex on feather weight at 19 and 44 days of age

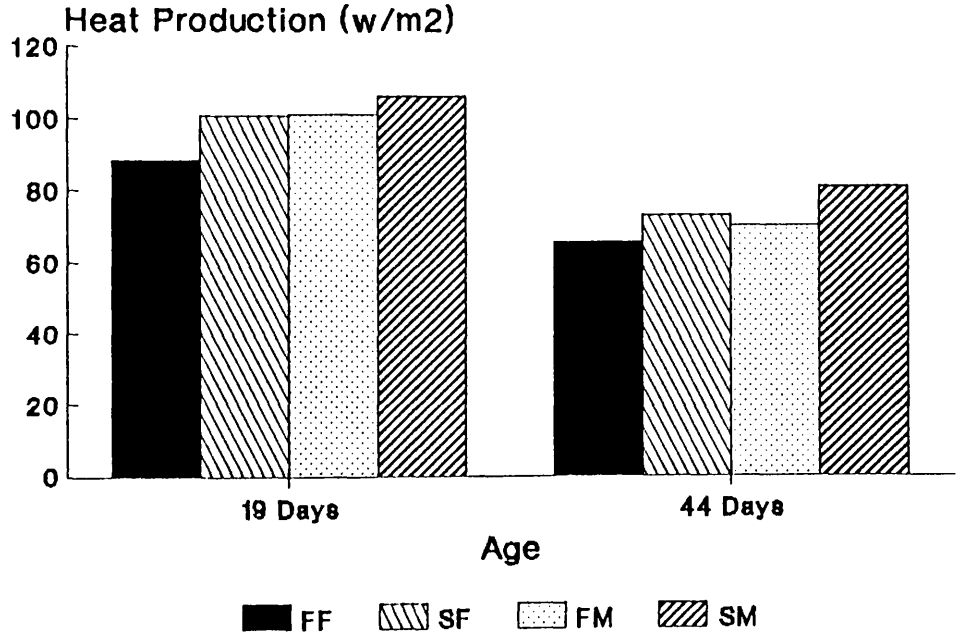


Figure 10.2. Effects of line and sex on heat production at 19 and 44 days of age

X.2.5. Energy and Nitrogen Intake and Retention

No significant difference was seen between the lines in the gross energy intake, apparent metabolisable energy (AME) intake, apparent metabolisability and nitrogen intake and faecal+urinary energy and nitrogen losses. Males had higher gross energy intake, AME intake, nitrogen intake and faecal+urinary energy and nitrogen losses than females (Table 10.4).

The energy, nitrogen and crude protein retention are presented in Table 10.5. At 19 days of age, the total energy retention and crude protein retention of the fast feathering line was higher than that in the slow feathering line. But at 44 days of age it was opposite (Fig. 10.3.). The partition of retained energy at 19 and 44 days of age indicated that the fast line retained more energy as fat and conversely less energy as body protein (per cent of the total retained energy) (Fig. 10.4).

X.4. DISCUSSION

This experiment was conducted over 5 weeks using calorimeter chambers, when the birds were between 14 and 45 days of age. Males and females of fast, control and slow feathering lines were used, but one of these line/sex combinations was omitted in each 3 day run in the calorimeters due to only 5 chambers being available. The effect of age, sex and line on rectal, skin, and feather

Table 10.4. Effects of age, line and sex on energy and nitrogen intake and losses

Line/ Sex	Age (Days)	Feed Intake g/d	Gross Energy Intake kJ/d	Faecal+ Urinary Energy Losses kJ/d	AME Intake kJ/d	Apparent Metabolisability	Nitrogen Intake g/d	Faecal+ Urinary Nitrogen Losses g/d
FF	16	51.88	876	235	641	0.73	1.87	0.96
	19	59.67	1008	253	755	0.75	2.15	1.07
	26	86.02	1434	367	1067	0.74	3.06	1.83
	30	76.33	1289	376	913	0.71	2.75	1.37
	33	-	-	-	-	-	-	-
	37	87.48	1478	414	1064	0.72	3.15	1.93
	40	102.52	1832	462	1370	0.75	3.90	2.35
	44	91.52	1635	368	1267	0.78	3.48	2.10
FM	16	54.23	916	264	652	0.71	1.95	1.11
	19	76.87	1298	368	930	0.72	2.77	1.53
	26	75.67	1278	308	970	0.76	2.72	1.57
	30	-	-	-	-	-	-	-
	33	99.78	1685	456	1229	0.73	3.59	2.22
	37	102.77	1736	422	1314	0.76	3.70	1.99
	40	114.87	2053	567	1486	0.72	4.37	2.64
	44	125.03	2234	503	1731	0.78	4.75	2.80
SF	16	48.83	825	249	576	0.70	1.76	0.98
	19	54.23	916	232	684	0.75	1.95	1.12
	26	77.22	1304	245	1059	0.81	2.78	1.34
	30	74.70	1262	308	954	0.76	2.69	1.52
	33	86.30	1458	361	1097	0.75	3.11	1.77
	37	-	-	-	-	-	-	-
	40	92.97	1661	417	1244	0.75	3.53	2.10
	44	106.50	1903	403	1500	0.79	4.05	2.09
SM	16	46.62	787	232	555	0.71	1.68	0.90
	19	66.60	1125	316	809	0.72	2.40	1.18
	26	-	-	-	-	-	-	-
	30	71.58	1209	294	915	0.76	2.58	1.62
	33	93.52	1580	423	1203	0.73	3.37	2.29
	37	104.42	1764	466	1298	0.74	3.76	2.37
	40	111.32	1989	557	1432	0.72	4.23	2.81
	44	138.30	2471	609	1862	0.75	5.26	2.84
CF	16	49.67	839	266	573	0.68	1.79	0.96
	19	-	-	-	-	-	-	-
	26	79.23	1338	271	1067	0.80	2.85	1.14
	30	79.23	1338	300	1038	0.78	2.85	1.50
	33	84.52	1428	398	1030	0.72	3.04	1.83
	37	90.60	1530	380	1150	0.75	3.26	1.77
	40	96.45	1724	395	1329	0.77	3.67	1.91
	44	-	-	-	-	-	-	-

FF= Fast Female; FM= Fast Male; SF= Slow Female; SM= Slow Male; Cf= Control Female

(.....continued)

Table 10.4. (continued)

Line/ Sex	Age (Days)	Feed Intake g/d	Gross Energy Intake kJ/d	Faecal+ Urinary Energy Losses kJ/d	AME Intake kJ/d	Apparent Metabolisability	Nitrogen Intake g/d	Faecal+ Urinary Nitrogen Losses g/d
CM	16	-	-	-	-	-	-	-
	19	68.87	1163	305	858	0.74	2.47	1.21
	26	86.02	1453	372	1081	0.80	3.10	1.66
	30	94.48	1596	451	1145	0.72	3.40	2.06
	33	96.82	1635	432	1203	0.74	3.49	2.13
	37	101.55	1715	493	1222	0.71	3.66	2.20
	40	-	-	-	-	-	-	-
	44	120.27	2149	484	1665	0.78	4.57	2.35
SED		3.65	62.50	25.62	46.70	0.01	0.13	1.35
MAIN EFFECTS								
Age -	16	50.20	849	249	599	0.71	1.81	0.98
	19	65.20	1102	295	807	0.73	2.35	1.22
	26	82.60	1361	313	1049	0.77	2.90	1.51
	30	79.30	1339	346	993	0.74	2.85	1.61
	33	92.20	1557	414	1143	0.73	3.32	2.05
	37	101.40	1645	435	1210	0.74	3.51	2.05
	40	103.60	1852	480	1372	0.74	3.94	2.36
	44	116.30	2078	473	1605	0.77	4.42	2.43
SED		4.47	61.20	25.10	45.80	0.01	0.13	0.12
Line -	Fast	86.05	1482	383	1099	0.74	3.16	1.75
	Slow	83.79	1447	365	1085	0.75	3.08	1.78
	Control	87.31	1492	379	1113	0.75	3.18	1.73
SED		3.23	44.20	18.11	33.00	0.01	0.09	0.08
Sex -	Male	92.48	1592	416	1178	0.74	3.39	1.97
	Female	78.79	1354	335	1019	0.75	2.88	1.58
SED		2.64	36.10	14.79	27.00	0.01	0.08	0.07
Significance of Differences:								
Age (A)		***	***	***	***	*	***	***
Line (L)		NS	NS	NS	NS	NS	NS	NS
Sex (S)		***	***	***	***	*	***	***
L x S		NS	NS	NS	NS	NS	NS	NS

NS = Non Significant; * = P < 0.05; *** = P < 0.001

CM = Control Male

Table 10.5. Effects of Age, Line and Sex on Energy and Protein Retention

Line/ Sex	Age (Days)	Total Energy Retention kJ/d	Nitrogen Retention g/d	Crude Protein Retention g/d	Energy Retained as Protein kJ/d	Energy Retained as Fat kJ/d
FF	16	239.87	0.91	5.70	135.09	104.78
	19	320.26	1.08	6.76	160.12	160.14
	26	464.98	1.23	7.66	181.45	283.53
	30	388.90	1.38	8.60	203.82	185.08
	33	-	-	-	-	-
	37	507.93	1.22	7.64	181.16	326.77
	40	661.51	1.55	9.67	229.16	432.35
	44	517.96	1.38	8.61	204.13	313.83
FM	16	221.56	0.84	5.24	124.14	97.42
	19	413.38	1.24	7.74	183.53	229.85
	26	336.67	1.16	7.24	171.54	165.13
	30	-	-	-	-	-
	33	428.67	1.38	8.61	203.96	224.71
	37	609.11	1.71	10.68	253.00	356.11
	40	750.53	1.73	10.78	255.51	495.02
	44	818.61	1.96	12.23	289.73	528.88
SF	16	213.90	0.78	4.87	115.44	98.46
	19	233.67	0.83	5.19	123.10	110.57
	26	452.09	1.44	9.02	213.75	238.34
	30	468.26	1.17	7.30	173.01	135.35
	33	292.53	1.34	8.38	198.63	93.90
	37	-	-	-	-	-
	40	490.07	1.43	8.95	212.12	277.95
	44	665.90	1.96	12.26	290.47	375.43
SM	16	184.13	0.78	4.88	115.54	68.59
	19	291.47	1.22	7.62	180.57	110.90
	26	-	-	-	-	-
	30	196.34	0.96	5.99	141.92	54.42
	33	275.24	1.07	6.71	158.93	116.31
	37	404.32	1.39	8.66	205.15	199.17
	40	559.14	1.42	8.90	210.93	348.21
	44	865.45	2.42	15.12	358.32	507.13
CF	16	206.45	0.83	5.16	122.36	84.09
	19	-	-	-	-	-
	26	513.65	1.71	10.69	253.45	260.20
	30	468.26	1.35	8.46	200.57	267.69
	33	317.45	1.21	7.56	179.08	138.37
	37	445.65	1.49	9.31	220.72	224.93
	40	701.91	1.75	10.95	259.52	442.39
	44	-	-	-	-	-

FF= Fast Female; FM= Fast Male; SF= Slow Female; SM= Slow Male;
CF= Control Female

(.....continued)

Table 10.5. (continued)

Line/ Sex	Age (Days)	Total Energy Retention kJ/d	Nitrogen Retention g/d	Crude Protein Retention g/d	Energy Retained as Protein kJ/d	Energy Retained as Fat kJ/d
CM	16	-	-	-	-	-
	19	396.97	1.26	7.88	186.78	210.19
	26	415.21	1.44	9.01	213.61	201.60
	30	325.91	1.34	8.39	198.80	127.11
	33	387.32	1.35	8.46	200.57	186.75
	37	591.37	1.46	9.09	215.53	375.84
	40	-	-	-	-	-
	44	662.97	2.22	13.87	328.70	334.27
SED		43.40	0.10	0.64	15.04	35.15
MAIN EFFECTS						
Age -	16	213.0	0.83	5.17	122.5	90.7
	19	331.0	1.13	7.04	166.8	164.3
	26	437.0	1.40	8.72	206.8	229.8
	30	338.0	1.24	7.75	183.6	153.9
	33	340.0	1.27	7.94	188.2	152.0
	37	512.0	1.45	9.08	215.1	296.6
	40	633.0	1.58	9.85	233.4	399.2
	44	706.0	1.99	12.42	294.3	412.0
SED		42.5	0.10	0.62	14.74	34.40
Line -	Fast	477.14	1.34	8.37	198.31	278.83
	Slow	399.47	1.30	8.13	192.70	195.34
	Control	452.76	1.45	9.07	214.97	237.79
SED		30.70	0.07	0.45	10.63	24.86
Sex -	Male	456.72	1.42	8.86	209.84	246.88
	Female	428.56	1.30	8.14	192.86	227.71
SED		25.10	0.06	0.37	8.68	20.30
Significance of Differences:						
Age (A)		***	**	**	**	***
Line (L)		**	*	*	*	**
Sex (S)		NS	NS	NS	NS	NS
L x S		NS	NS	NS	NS	NS

NS = Non Significant; * = P < 0.05; ** = P < 0.01; *** = P < 0.001
CM = Control Male

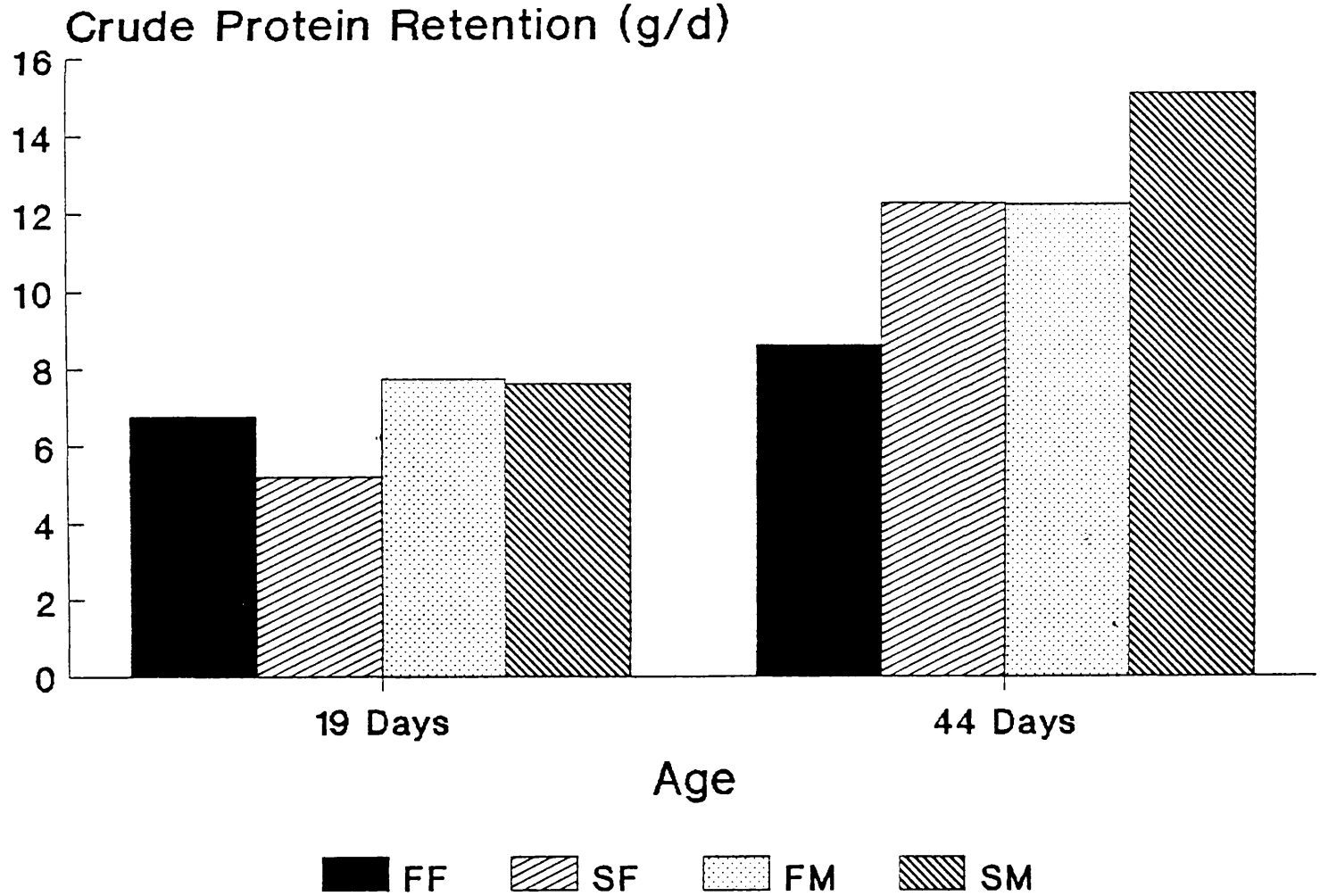


Figure 10.3. Effects of line and sex on crude protein retention at 19 and 44 days of age.
FF= Fast Female; FM= Fast Male; SF= Slow Female; SM= Slow Male

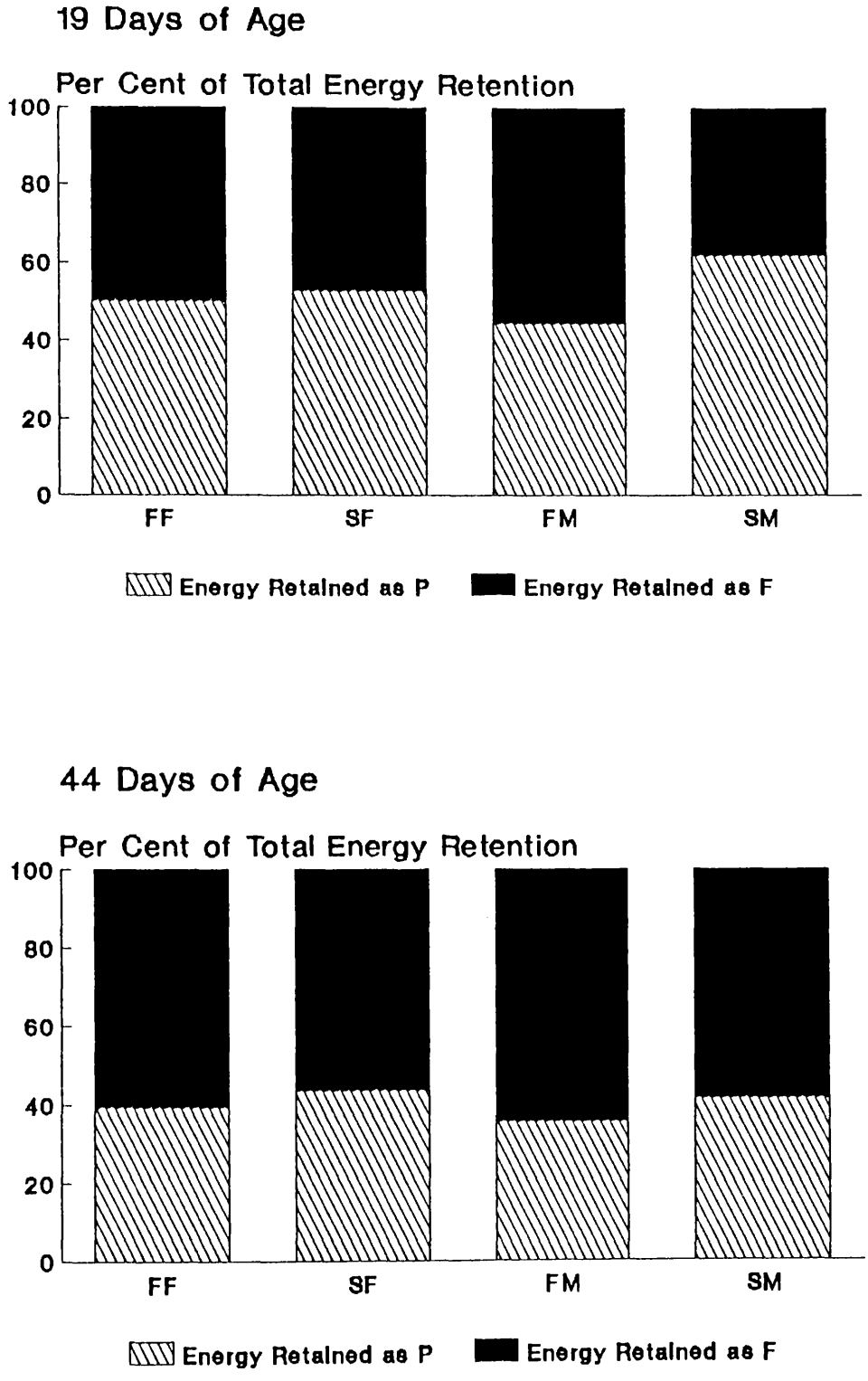


Figure 10.4. Effects of line and sex on energy retained as protein and fat (per cent of total energy retention) at 19 and 44 days of age.
FF= Fast Female; FM= Fast Male; SF= Slow Female; SM= Slow Male; P= Protein; F= Fat

surface temperature and thermal resistance of the feathers will be discussed. Furthermore, the importance of feather cover on heat production and energy metabolism will also be discussed.

X.4.1. Effect of Age

The rectal, skin and surface temperature were affected by age. Although in general the rectal temperature seemed to increase with age, the effect was not so obvious. The reason may be due to rectal temperature measuremens were started when the birds already more than 2 weeks old, and not from hatched chicks. This result is in agreement with Lamoreux and Hutt (1939) who reported that the body temperatures of hatched chicks are lower than those of mature birds, but they increase progressively until the adult levels are reached at an age of approximately 20 days, depending on the breed.

The increase in the temperature of the skin ($0.03^{o}C/d$) underlying the feathered back and decrease in the surface temperature of feathers ($0.3^{o}C/d$) with age appear to be associated with the increase in feather weight (3.1 g/d), and thus the increase in thermal resistance of the feathers (0.15/d) and with the decrease in the heat production (1.4 W/m^2). However, the heat production (W/m^2) reaches a maximum value occurs between 2 and 3 weeks of age. Balnave (1974), in a review of the effect of age on metabolic rate of the growing fowl, concluded that the basal metabolic rate per

unit of metabolic body weight reaches a maximum value between 2 and 5 weeks of age. Medway and Kare (1957) observed a high basal metabolic rate for young chickens aged 14 to 28 d, associated with the change to feather cover. Furthermore, Deschutter and Leeson (1986) reported that the increase in heat production was greater in 5-wk-old than in 7-wk-old chickens, this may have been related to the poorer feathering.

The increase in body weight (44 g/d) with age will increase in feed intake (1.8 g/d), water intake (3.4 ml/d), gross energy intake (35.7 kJ/d), apparent metabolisable energy (AME) intake (27.0 kJ/d), nitrogen intake (0.08 g/d), total energy retention (14.4 g/d), nitrogen retention (0.02 g/d), energy retained as protein (3.2 kJ/d) and energy retained as fat (11.2 kJ/d). Fuller (1969) stated that growing animals are characterised by high rates of synthesis of tissue proteins, the form in which a large fraction of their dietary protein is retained. Jorgensen (1989) reported that the fat retention increases with increasing liveweight.

X.4.2. Effect of Sex

There was no significant difference in rectal temperature between males and females. Males had slightly higher skin and surface temperatures than females. The difference in the skin and surface temperatures may be due to females having more feathers than males. Because of this, males had lower thermal resistance of the feathers than the

females. Furthermore, heat production in the males was higher than in the females.

Males had a higher body weight, feed intake and water intake than the females. Generally females had greater absolute feather weight and feather weight as a percentage of body weight and, longer feather lengths than males. This meant that males had higher defeathered body weights than females.

Males had a higher gross energy intake and apparent metabolisable intake than females, but females had slightly higher in apparent metabolisability than in the males.

There were no differences in total energy retention, energy retention as fat and energy retention as protein between males and females. However, males had a higher nitrogen intake than females, by virtue of a higher feed intake. The nitrogen or crude protein retention was not different between males and females.

Males had a higher meat weight and the whole carcass minus feathers + meat weight than females. However, meat as a percentage of live body weight was not significantly different between males and females. Abdominal fat in females and males was also not different.

Meat and defeathered carcass protein was higher in males than in females. However females had higher feather protein than males. But meat and defeatherd carcass protein as a percentage of live body weight was not different between males and females. Feather protein as a percentage of live body weight was higher in females than in males.

X.4.3. Effect of Line

There were no significant differences in rectal temperature between fast and slow feathering lines. However, the slow feathering line had 0.8^{o}C lower skin temperature but 5^{o}C higher feather surface temperature than fast and control feathering lines.

The importance of feathers for conservation of heat can be explained from the results of thermal resistance of the feathers. Since slow feathering line had poor cover feathering, they had 1.6 and 2 s/cm lower thermal resistance of the feathers than control and fast feathering lines, respectively.

The condition of feathering also can be associated with heat production. Slow feathering line had 10.8 and 15.1 W/m^2 higher heat production than control and fast feathering lines, respectively. The highest difference in heat production between lines in both sexes was appeared at about 3 weeks of age. Since at this age, the difference on feathering also most pronounced.

No significant difference was found in feed and water intake between lines. Although the fast line had a higher gross energy intake than slow line, there was no difference in AME intake between lines. This result is in agreement with Pym (1985) who stated that the genetic variation in digestibility or metabolisability of nutrients between strains or breeds is generally believed to be of minor importance. Geraert *et al.* (1988) and MacLeod *et al.* (1988) reported that metabolisable energy intake did not differ

significantly between the fat and lean lines.

The fast feathering line had higher total energy retention than the slow line but was no different to the control line. However, the partition of retained energy between fat and protein (per cent of retained energy) demonstrated that the fast feathering line had higher per cent of retained energy as fat than control and slow feathering lines (57.6% vs 54.3% and 48.4%, respectively), but slow feathering line had higher per cent of retained energy as protein than the control and fast feathering lines (51.6% vs 45.7% and 42.4%, respectively). This result is supported by Geraert *et al.* (1988) and MacLeod *et al.* (1988) who stated that the essential difference between the lines (lean and fat lines) was the partition of the same quantity of retained energy between fat and protein deposition. Brody (1935) predicted that low efficiency strains would store less protein and more fat than high efficiency strains. Furthermore, the difference on nitrogen intake and nitrogen retention between fast and slow feathering lines were not significantly different.

CHAPTER XI. GENERAL DISCUSSION

XI.1. The Effects of Divergent Selection for Feather Growth on the Broiler

Selection for feather growth based on the tail length at around three weeks of age has been effective. After four generations of selection it has been demonstrated that the growth characteristics of all feather tracts have been changed. The mature length of feathers are greater in the fast line and the total weight of plumage is greater. It is clear that slow feathering has several consequences:

1. A delayed onset of the growth of all tracts
2. A similar rate of growth of most tracts but a reduced rate in some tracts, and a reduced plumage weight
3. Shorter final length of most tracts and a reduced plumage weight
4. A delayed onset of the first moult and slower progress of the moult.

Thus selection for feather length has been, in the main, a selection for control of the initiation of feather development of the broiler. Not only has the beginning of feather growth been altered but also a slower rate of growth in some tracts and the onset of the first moult. The feathering characteristics associated with so-called poor or good feathering seem to be comprehensive for the whole of the control of feather growth and moulting. Since the intensity of selection has been greater in the male than the female it was expected that the male would show a greater

overall change in feather growth.

Most of the observed differences would be due to the additive genes influencing feathering but there is good evidence to suggest that another allele of the k^+ series, possibly K^S, is now present in the population. Had less vigilance been exercised in the examination of feathers during each generation of selection at hatching time it is probable that the k^+ gene would have been present now as well. All chicks which were suspected to be carrying the k^+ gene were removed. This gene is always identifiable in the female progeny, (k-), since due to sex-linkage it is masked in the male progeny by the dominant K (Kk). In the fourth generation a possible k^+ revertant was saved for investigation when an adult.

XI.2. Broiler Characteristics

Across all the experiments carried out in this study, and the associated studies of Molanapour (1988) and Ajang (1989) the body weight of the males and females of the slow feathering line has been shown to be slightly less than that of the fast feathering line. However, in the two studies where full evaluation of the lines as broilers, using diets adequate in methionine (Ajang, 1989; experiment 2 this study) if not in cystine (experiment 2) the slow line birds have exceeded the fast line birds in the important broiler traits, body weight and feed conversion ratio. In the experiments where the fast line birds exceeded the slow line

in performance much of the difference could be accounted for by the head start the fast line birds get by virtue of their higher day-old weight.

A reduced rate of feathering does not have a detrimental effect for the main economic characters of a broiler, body weight and feed conversion ratio and therefore there is a good reason for breeding companies to adjust the rate of feathering to optimise other broiler traits.

The condition of the breast and back skin are important for carcass quality. In the experiments conducted in this study neither of these skin areas in the slow line birds were noticed to be unduly harmed or to have more skin blemishes. The conditions of rearing were extremely favourable for good skin condition and could not be regarded as typical commercial broiler rearing situations. Therefore it is not possible to make a critical comment in respect of feathering condition and skin quality.

Ease of feather removal is important in the processing of broiler carcasses especially where the carcass is to be sold whole. Feather removal from slow or fast line birds by the plucking machine in the Poultry Science Department has not been found to be more or less difficult in this study or those of Edriss (1988), Molanapour (1988) or Ajang (1989). Even when the slowest feathering males are killed at typical broiler weights the feathers are removed by the single stage plucker. Most commercial slaughter lines have at least a three-stage plucker. Further research would be needed using commercial stocking densities and litter conditions to

evaluate the role of feather condition on back and breast blemishes in a slow feathering line.

XI.3. Layer Characteristics

While the study did not focus primarily on the performance of the adults as breeders the single evaluation of egg production and egg weight indicated egg production was superior and egg weight inferior in the slow line. The peak level of performance (80% hen-day egg production) achieved by the slow line was high in commercial terms for a parent line; the fact that this line is not a cross and that selection for egg production has been suspended for four generations makes it outstanding.

Although it is possible to state that this might be a pleiotropic effect further records of egg production will be needed to establish that the slow line consistently produces eggs at a higher rate than the fast line. The smaller eggs produced by the slow dams place the slow progeny at a disadvantage in a broiler performance trial. Nevertheless if the higher performance of the slow dam is repeatable then the smaller egg weight would be more than balanced by more eggs. Furthermore a smaller egg would be welcomed by the hatchery manager at the closing stages of the breeding period when egg weight often exceeds 75 g. The large eggs are difficult to place side by side in hatcher trays thus lessening the incubator setter capacity.

XI.4. Energy and Protein Metabolism

A poorer feather covering has generally been regarded as a deleterious trait in energy and feed efficiency terms alone. All of the data produced by other researchers (e.g. O'Neill *et al.*, 1971, 1974; Richards, 1977; Tullet *et al.*, 1980) for adult fowl have focused on the increase in heat production and the correlated increase in feed intake when the cover of feathers has been compromised in any way; either through artificial removal or by wear and tear. In the experiments of the current study which may be regarded as realistic in terms of diet specification and broiler performance, birds in the slow and fast lines have had a similar feed intake.

It is clear that a slower development of feathering which leads to an increase in heat production did not produce an increase in feed intake. This was an unexpected result and is difficult to explain in terms of conventional models of energy metabolism and feed intake control. The extra loss of energy to the environment by the slow feathering birds can be accounted for by the decrease in deposition of fat. The accompanying decrease in weight gain because less adipose tissue is synthesised is counteracted by the weight gain due to the increase in lean tissue synthesis. Thus through this mechanism the slow line birds are able to preserve their FCR at a level similar to that of the fast line.

The higher meat yield of the slow line makes it a more valuable carcass even with a similar dressed carcass percentage. Since the slow line contains less fat, the carcass meat yield may be expected to be superior to the fast line and thus the slow line would have a more valuable carcass, even with a slightly lighter weight-for-age. Thus the slow line birds, starting lighter at day old and ending up lighter at market age, could still be a more attractive bird in terms of leaner meat yield.

Evidence has been presented in experiments 6 and 7 that the slow feathering broilers produce more meat protein than fast feathering broilers. Likewise evidence of a similar nature concerning the effect of the Naked Neck gene demonstrated that more meat is produced in stocks with NaNa in the genotype. Clearly there must be a mechanism whereby the amino acids in the body pool are being directed to produce more body protein. All the measurements of feather growth point to the fact that the onset of growth in all tracts is delayed in the slow line relative to that in the fast line. Once all the feathers have commenced growing the rate of growth of most of the tracts in the two lines appear to be very much the same. However until all feathers have commenced growing at a maximum rate the slow line would commit less of the amino acid pool to feather synthesis. In the slow line most feathers had reached maximum growth rate by 20 days of age. This difference is enough to change the protein metabolism in the slow line so more carcass protein is deposited. Once the subtle alterations in protein

metabolism are effected, the slow line diverges permanently from the fast line in terms of carcass protein. A similar mechanism may be envisaged in the stocks carrying the Naked Neck gene except that the NaNa birds produce less feathers from day old.

The mechanism whereby this takes place could be at many locations in the complexity of the whole body protein metabolism. Many of the possible controls of protein metabolism have been outlined by Reeds (1987). Among these possible controls it is reasonable to state that the slow line birds have an increased supply of amino acids in the body pools. Changes in the balance of rates of secretion of the hormones controlling protein metabolism, viz. thyroxine, insulin , growth hormone and glucocorticoids, then produce the increased deposition of meat protein.

The effect of a change in the balance of hormones has on the expression of genes is illustrated in Plates 11.1 and 11.2. Hens which had been through a moult produced feathers with a greater intensity of colour and more vane and less fluff (see also Fig. 2.4.) than hens which regrew feathers while still producing eggs.

XI.5. Sulphur Amino Acid Requirement

Slow feathering line required higher SAA than fast feathering line for body and feather growth. They almost have the same cystine requirement for body growth, but slow feathering females required higher cystine than slow

Plate 11.1. A hen which was almost bare of feathers and which had stopped laying, moulted and recommenced egg production.

Plate 11.2. A hen which was almost bare of feathers and which regrew feathers while continuing to lay eggs.

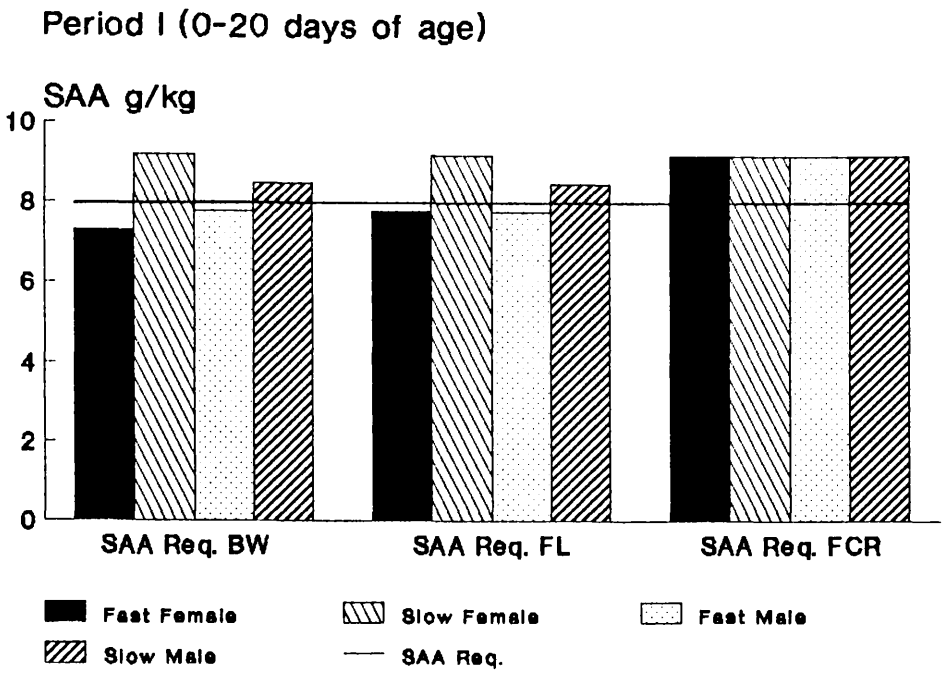
feathering males and both sexes of fast feathering line for feather growth.

The differences in sulphur amino acid requirements could be due to several factors.

1. The lines have different rates of catabolism of cystine and/or methionine
2. The increased amount of body protein would have a higher maintenance need
3. The changed balance of circulating hormones may also increase maintenance need
4. A higher rate of synthesis of body protein

The difference in SAA requirements between the fast and slow lines may be likened to the differences between the sexes. Males have more meat and less fat than females and have a higher SAA requirement - this is precisely the situation that exists between the fast and slow lines.

Generally, the SAA requirement of males and females of slow feathering line and the cystine requirement of slow feathering females were found to be higher than published SAA and cystine requirements (Fig. 11.1. and Fig. 11.2.). It seems that selection for fast feathering generally decreases SAA and cystine requirements for maximum growth relative to published values.



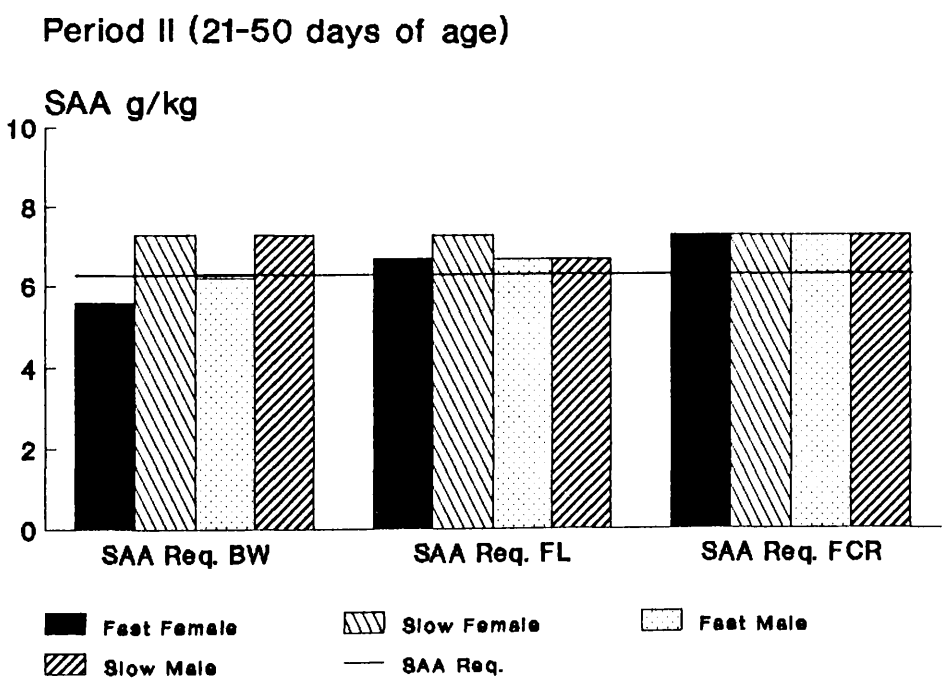
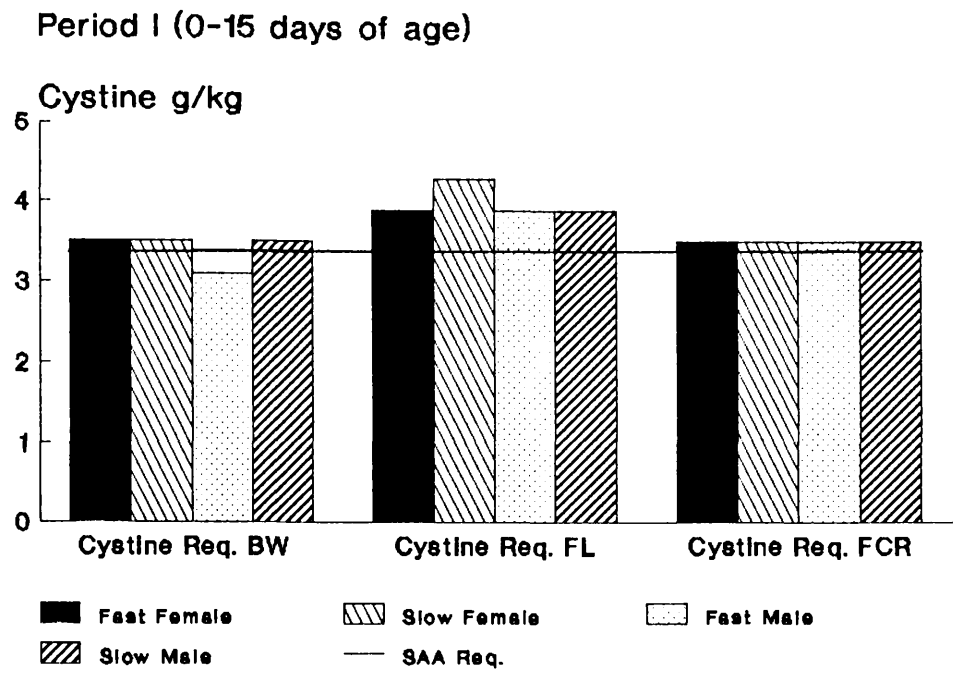


Figure 11.1. Sulphur amino acids (SAA) requirements for fast and slow feathering lines.
SAA= sulphur amino acid; Req.= requirement; BW = body weight; FL= feather length; FCR= feed conversion ratio



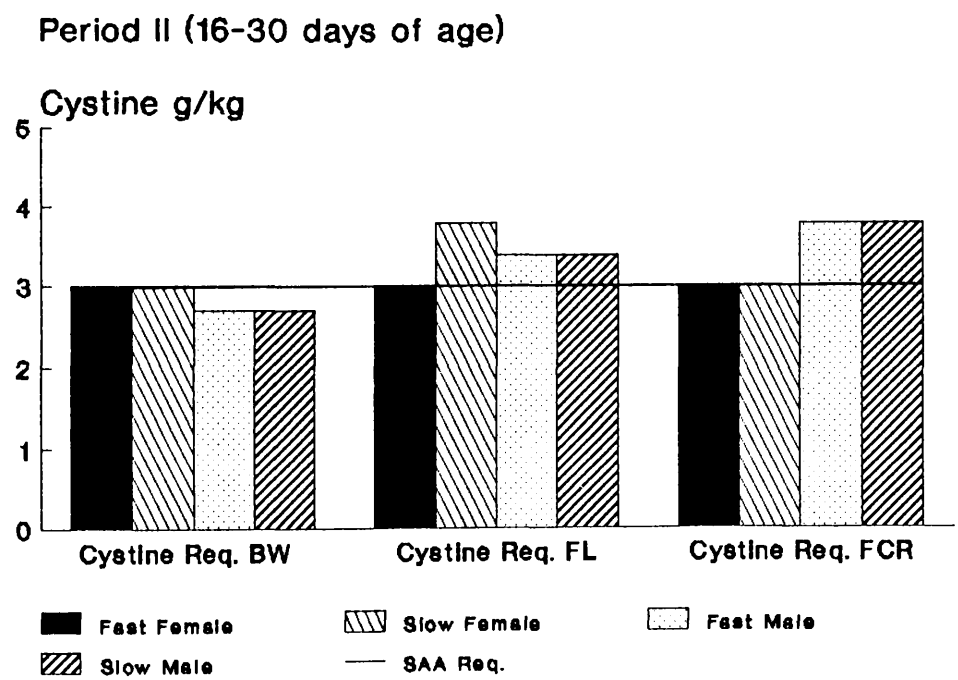


Figure 11.2. Cystine requirement for fast and slow feathering lines.
Req.= requirement; BW = body weight; FL= feather length; FCR= feed conversion ratio

CHAPTER XII. CONCLUSION

From the main findings in the various experiments on the growth and egg production in lines of meat chickens for fast and slow feathering the following conclusions may be drawn:

1. The effects of selection for feather growth based on flight, back and tail feathers were seen in all feather tracts. The responses varied among the feather tracts. Some tracts showed line differences only in the age of emergence of the feathers while others also showed line differences in the rate of growth. Selection also produced line differences in the age of onset of the first moult.

2. Selection for slow growth may have allowed another major feathering gene to increase in frequency and to be segregating with the K gene.

3. The condition of feathers at 14 days of age is a good time to distinguish between fast and slow lines and between sexes in both lines.

4. The slow line had a higher rate of egg production with smaller eggs and a slightly higher egg mass output. The smaller eggs gave smaller chicks and in most but not all of the experiments the smaller day old weight penalised final body weights.

5. The selection for feather growth produced line differences in the quantity of feathers and the level of

resistance to heat loss. As a result line differences in heat production were created.

6. When slow feathering birds are reared in a thermoneutral environment the feed conversion ratio is similar to that of fast feathering birds. The situation may change when birds are reared in either a hot or cool environment. Differences in feather insulation does not produce a change in feed intake in rapidly growing broilers.

7. The total amount of protein in the bodies of slow and fast feathering birds is the same but when the protein is partitioned slow feathering birds have more protein in the carcass and less in feathers. The fast feathering birds retain more energy as fat than slow feathering birds. At all weights up to about 2 kg the slow feathering birds had a higher meat yield and are therefore of more value as a broiler.

8. Slow feathering birds generally, and in particular females, have a higher sulphur amino acid and cystine requirement than fast feathering birds for maximum growth but not feed efficiency. These higher requirements are affected by age and growth trait. Selection for fast feathering generally decreases SAA and cystine requirements for maximum growth relative to published values.

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APPENDICES

APPENDIX 1

Feed intake, sulphur amino acid intake, feed conversion ratio and body weight during 0-50 days of age (experiment 1)

Days	Diet	Cumulative Feed Intake (g/b/d)		Cumulative SAA Intake (mg/b/d)		FCR [1]		Mean Body Weight (gram)			
		Fast	Slow	Fast	Slow	Fast	Slow	Fast		Slow	
								F	M	F	M
1	-	-	-	-	-	-	-	41.5	41.8	37.8	38.6
10	1	16.96	17.94	98.0	104.0	1.51	1.69	150.9	155.7	140.5	148.2
	2	18.20	20.22	120.0	133.0	1.47	1.61	162.9	166.7	151.9	174.9
	3	18.64	20.32	136.0	148.0	1.44	1.53	172.9	171.3	165.5	174.8
	4	18.82	19.42	147.0	151.0	1.36	1.43	178.7	182.5	174.2	173.0
	5	18.00	18.84	153.0	160.0	1.25	1.43	184.8	189.0	164.2	171.6
	6	16.96	18.00	156.0	166.0	1.24	1.40	181.3	177.2	162.3	171.1
20	1	38.10	39.90	220.8	231.3	1.90	2.04	427.7	457.8	408.9	451.0
	2	38.38	40.99	253.2	270.3	1.84	1.92	440.4	480.0	440.4	489.1
	3	42.54	43.16	310.5	314.8	1.79	1.87	497.0	537.5	469.2	525.4
	4	41.44	42.08	323.5	327.8	1.71	1.81	497.1	555.3	481.3	526.4
	5	40.81	42.55	346.8	361.7	1.73	1.80	481.3	547.6	480.7	542.2
	6	37.31	38.49	343.2	354.3	1.66	1.64	474.6	510.5	487.6	525.2
30	1	50.96	55.71	264.8	288.2	1.99	2.22	751.2	863.2	725.0	856.3
	2	51.23	60.23	302.2	351.3	1.95	2.08	758.1	902.3	849.7	966.0
	3	58.26	62.74	374.4	400.1	1.87	2.04	929.0	1023.0	908.3	1014.2
	4	57.89	60.83	403.3	421.9	1.81	1.97	946.4	1049.0	933.2	995.4
	5	59.15	65.56	445.2	490.3	1.81	2.12	967.5	1078.3	932.3	997.8
	6	54.47	56.61	444.8	462.1	1.65	1.78	977.5	1090.8	943.0	1038.2
40	1	67.03	73.85	331.0	363.7	2.45	2.67	1054.3	1248.4	1017.0	1269.8
	2	70.48	79.28	393.3	440.8	2.33	2.50	1164.9	1341.6	1198.8	1417.3
	3	77.70	81.45	471.3	492.7	2.22	2.42	1372.4	1514.9	1268.3	1473.0
	4	75.96	80.89	504.3	535.0	2.12	2.37	1369.4	1572.7	1325.2	1478.7
	5	77.99	86.47	559.2	617.7	2.24	2.49	1324.6	1538.7	1335.4	1546.7
	6	68.69	73.68	636.8	574.5	1.96	2.14	1329.4	1562.4	1335.8	1496.3
50	1	84.41	91.16	406.4	438.5	2.70	2.90	1420.4	1785.4	1421.2	1803.1
	2	86.51	93.91	471.3	511.2	2.46	2.70	1647.7	1952.5	1635.4	1920.7
	3	91.81	94.92	543.1	560.8	2.34	2.61	1862.1	2140.5	1747.6	1941.6
	4	90.65	91.84	588.7	596.1	2.27	2.54	1844.1	2236.7	1752.8	1942.5
	5	91.20	99.73	640.3	698.9	2.34	2.62	1773.8	2204.5	1745.7	2131.8
	6	82.61	88.99	631.3	678.9	2.11	2.28	1773.5	2190.4	1805.5	2182.6

1) FCR = Feed Conversion Ratio = g feed/g body weight gain

F = Female, M = Male

(.....continued)

APPENDIX 1
(continued)

	Cumulative Feed Intake (g/b/d)	Cumulative SAA Intake (mg/b/d)	FCR	Mean Body Weight (gram)
MAIN EFFECTS				
Age - 1	-	-	-	39.9
10	18.53	139.33	1.45	168.6
20	40.48	304.86	1.81	488.9
30	57.80	387.40	1.94	937.3
40	76.12	485.00	2.33	1356.5
50	90.65	563.81	2.49	1869.3
SED	0.43	2.69	0.01	3.65
Diet - 1	53.60	274.68	2.21	696.5
2	55.94	324.67	2.09	767.5
3	59.15	375.17	2.02	836.0
4	57.98	399.87	1.94	849.0
5	60.03	447.32	1.98	854.1
6	53.58	434.79	1.79	857.3
SED	0.47	2.95	0.02	3.65
Line - Fast	54.77	363.99	1.92	820.0
- Slow	58.66	388.17	2.09	800.1
SED	0.27	1.70	0.01	2.11
Sex - Male	-	-	-	867.4
Female	-	-	-	752.8
SED				2.11
Significance of Differences:				
Age (A)	***	***	***	***
Diet (D)	***	***	***	***
Line (L)	***	***	***	***
Sex (S)	-	-	-	***
A x D	***	***	***	***
A x L	***	***	***	***
D x L	***	***	*	***
A x S	-	-	-	***
D x S	-	-	-	***
L x S	-	-	-	*
A x D x L	NS	NS	NS	***
A x D x S	-	-	-	***
A x L x S	-	-	-	***
D x L x S	-	-	-	***
A x D x L x S	-	-	-	**

* = P < 0.05; ** = P < 0.01; *** = P < 0.001;
NS = Non Significant

APPENDIX 2

Primary and secondary wing feather lengths (experiment 1)

Days	Diet	Primary Feather Length (mm)				Secondary Feather Length (mm)			
		Fast		Slow		Fast		Slow	
		F	M	F	M	F	M	F	M
1	-	12.39	11.54	11.07	10.28	8.36	7.36	5.51	3.90
10	1	45.71	38.33	28.81	19.90	28.57	25.38	18.00	15.00
	2	45.71	40.43	29.48	21.86	28.95	26.71	19.95	15.86
	3	45.95	40.76	29.50	22.14	29.43	26.43	20.57	16.62
	4	47.67	44.38	29.57	22.52	31.62	29.19	21.19	16.95
	5	47.71	42.38	32.48	23.19	31.81	29.05	21.43	17.33
	6	46.34	39.09	32.81	23.43	31.14	25.95	23.38	18.62
20	1	81.43	78.43	69.24	60.52	67.38	58.24	46.67	37.14
	2	83.62	79.85	70.76	62.00	69.71	61.57	49.05	40.62
	3	85.43	83.00	70.95	64.62	71.14	65.33	49.19	40.67
	4	87.17	85.72	73.19	64.72	75.25	68.38	50.67	40.81
	5	85.43	82.86	73.19	67.57	73.19	66.29	55.00	44.52
	6	85.43	81.91	76.95	64.67	72.76	64.57	57.48	38.76
30	1	105.09	104.62	99.38	93.85	98.95	90.70	80.81	66.24
	2	105.62	107.81	101.48	91.67	99.81	95.57	84.24	70.52
	3	109.62	113.81	101.48	96.48	103.81	101.76	86.10	71.14
	4	111.93	114.67	104.38	102.90	107.44	104.76	87.38	71.52
	5	111.14	112.62	105.67	104.52	104.19	103.57	90.00	78.09
	6	110.86	112.00	108.72	97.81	103.57	101.24	94.81	70.05
40	1	123.05	127.08	122.48	120.76	121.86	121.38	111.67	98.57
	2	124.43	128.52	124.19	122.52	123.71	123.24	113.48	103.48
	3	127.71	132.52	124.38	126.53	127.43	129.62	115.38	108.23
	4	129.45	133.28	126.86	127.06	127.83	130.33	115.62	108.43
	5	129.50	133.70	127.14	129.16	128.00	130.24	116.52	109.81
	6	129.86	133.86	130.52	126.73	127.81	128.85	122.32	106.03
50	1	135.05	143.38	136.58	139.97	131.81	140.59	130.83	126.94
	2	136.05	144.33	137.91	140.27	134.38	143.11	133.50	126.78
	3	137.86	146.59	139.40	145.41	138.14	145.59	135.70	135.05
	4	138.81	147.02	140.52	145.51	138.24	146.92	135.91	136.36
	5	140.29	147.53	140.75	147.96	138.28	147.46	136.23	137.45
	6	139.47	144.39	143.24	146.26	138.62	146.93	140.63	132.97

F = Female, M = Male

APPENDIX 3

Tail and breast feather lengths (experiment 1)

Days	Diet	Tail Feather Length (mm)				Breast Feather Length (mm)			
		Fast		Slow		Fast		Slow	
		F	M	F	M	F	M	F	M
10	1	7.48	3.19	0.71	0.00	-	-	-	-
	2	8.72	4.48	1.57	0.19	-	-	-	-
	3	9.10	4.76	2.52	0.66	-	-	-	-
	4	9.85	5.95	3.05	0.43	-	-	-	-
	5	9.90	5.57	3.71	0.62	-	-	-	-
	6	11.57	4.90	2.95	0.00	-	-	-	-
20	1	27.71	15.95	10.33	6.43	28.33	28.71	20.09	14.57
	2	28.52	18.62	12.62	7.47	31.43	32.29	22.00	23.05
	3	31.67	19.24	13.24	7.81	33.76	32.86	25.43	23.34
	4	34.26	21.38	14.29	8.00	35.71	33.19	27.67	23.52
	5	34.10	19.52	17.29	9.28	37.52	34.28	30.91	26.00
	6	33.81	19.00	16.19	8.05	33.39	35.14	30.10	23.57
30	1	56.71	34.81	24.29	12.43	48.33	47.92	43.71	34.29
	2	58.19	39.14	29.19	19.81	53.33	49.05	46.14	39.72
	3	65.05	44.05	32.19	19.29	55.05	50.52	46.19	40.76
	4	69.67	47.43	32.85	20.52	57.51	53.24	47.86	41.38
	5	66.71	45.62	40.38	24.86	55.00	54.48	50.09	43.05
	6	65.00	42.33	40.38	18.86	53.57	53.29	53.05	42.43
40	1	89.71	62.29	53.57	29.48	59.19	59.72	58.09	51.62
	2	93.14	68.52	54.19	37.62	59.48	61.28	58.71	57.38
	3	99.62	72.88	59.86	37.91	62.95	69.70	60.81	58.44
	4	101.34	80.76	62.38	42.20	63.69	70.05	61.48	59.02
	5	101.48	76.79	70.19	45.01	65.05	68.35	62.10	61.93
	6	102.05	76.30	75.29	39.61	67.38	68.17	64.77	61.05
50	1	118.86	88.93	70.75	47.94	67.90	69.43	67.12	65.74
	2	119.62	93.63	75.28	57.81	69.09	70.58	70.79	69.00
	3	124.62	99.84	82.80	59.28	72.95	75.53	72.71	71.62
	4	128.95	108.79	85.91	61.95	69.98	73.28	73.53	72.17
	5	126.86	108.03	91.94	64.44	73.81	72.93	73.68	72.24
	6	127.24	107.40	99.68	57.99	75.86	72.81	75.65	72.05

F = Female, M = Male

APPENDIX 4

Breast and back feather score (experiment 1)

Days	Diet	Breast Feather Score				Back Feather Score			
		Fast		Slow		Fast		Slow	
		F	M	F	M	F	M	F	M
10	1	1.67	1.24	1.00	1.00	1.00	1.00	1.00	1.00
	2	1.86	1.34	1.19	1.00	1.00	1.00	1.00	1.00
	3	2.00	1.48	1.29	1.00	1.00	1.00	1.00	1.00
	4	2.38	1.95	1.31	1.00	1.00	1.00	1.00	1.00
	5	2.48	1.62	1.43	1.00	1.00	1.00	1.00	1.00
	6	2.09	1.33	1.43	1.00	1.00	1.00	1.00	1.00
20	1	6.00	5.81	4.38	2.95	3.67	3.24	2.10	1.43
	2	5.95	6.00	4.43	4.52	3.86	3.43	2.38	1.76
	3	6.00	6.00	5.43	4.76	4.81	4.14	3.14	1.95
	4	6.00	6.00	5.57	4.95	5.00	4.67	3.47	2.14
	5	6.00	5.95	5.67	5.28	4.67	4.19	3.72	2.14
	6	5.99	5.96	5.76	4.67	4.71	3.81	3.91	2.05
30	1	6.00	6.00	6.00	5.48	6.00	6.00	5.43	3.19
	2	6.00	6.00	6.00	5.86	6.00	6.00	5.57	4.28
	3	6.00	6.00	6.00	5.91	6.00	6.00	5.62	4.09
	4	6.00	6.00	6.00	5.95	6.00	6.00	5.72	4.10
	5	6.00	6.00	6.00	6.00	6.00	6.00	5.76	4.48
	6	6.00	6.00	6.00	5.81	6.00	6.00	5.86	4.10
40	1	6.00	6.00	6.00	5.81	6.00	6.00	6.00	5.05
	2	6.00	6.00	6.00	6.00	6.00	6.00	6.00	5.85
	3	6.00	6.00	6.00	6.00	6.00	6.00	6.00	5.67
	4	6.00	6.00	6.00	6.00	6.00	6.00	6.00	5.56
	5	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00
	6	6.00	6.00	6.00	5.95	6.00	6.00	6.00	5.45
50	1	6.00	6.00	6.00	6.00	6.00	6.00	6.00	5.94
	2	6.00	6.00	6.00	6.00	6.00	6.00	6.00	5.94
	3	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00
	4	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00
	5	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00
	6	6.00	6.00	6.00	6.00	6.00	6.00	6.00	5.94

F = Female, M = Male

APPENDIX 5

Mean of feather lengths and feather scores (Appendices 1-4)

	Feather Lengths (mm)				Feather Score	
	P	S	T	B	B	BK
MAIN EFFECTS						
Age - 1	11.3	6.3	0.0	0.0	1.0	1.0
10	35.0	23.7	4.3	0.0	1.5	1.0
20	75.8	56.9	18.1	28.6	5.4	3.4
30	105.3	90.3	39.6	48.3	6.0	5.4
40	127.6	118.7	68.0	62.1	6.0	5.9
50	141.9	137.4	92.0	71.7	6.0	6.0
SED	0.39	0.52	0.62	0.40	0.03	0.04
Diet - 1	79.9	68.5	31.7	31.9	4.1	3.6
2	81.0	70.3	34.5	33.9	4.3	3.7
3	82.9	72.6	36.9	35.5	4.3	3.8
4	84.3	73.8	39.2	35.9	4.4	3.9
5	84.6	74.3	40.1	36.7	4.4	3.9
6	84.2	73.8	39.5	36.9	4.3	3.8
SED	0.39	0.52	0.62	0.40	0.03	0.04
Line - Fast	86.7	78.9	47.2	37.1	4.5	4.0
Slow	78.9	65.6	26.7	33.2	4.2	3.5
SED	0.22	0.30	0.36	0.23	0.02	0.02
Sex - Male	82.2	70.1	30.4	34.5	4.2	3.6
Female	83.4	74.3	43.6	35.7	4.4	3.9
SED	0.22	0.30	0.36	0.23	0.02	0.02
Significance Difference:						
Age (A)	***	***	***	***	***	***
Diet (D)	***	***	***	***	***	***
Line (L)	***	***	***	***	***	***
Sex (S)	***	***	***	***	***	***
A x D	***	***	***	***	***	***
A x L	***	***	***	***	***	***
D x L	**	*	**	NS	***	*
A x S	***	***	***	***	***	***
D x S	***	***	***	NS	*	NS
L x S	***	***	***	***	**	***
A x D x L	NS	NS	NS	NS	***	NS
A x D x S	NS	NS	NS	NS	**	NS
A x L x S	***	***	***	***	***	***
D x L x S	NS	NS	**	NS	*	NS
A x D x L x S	NS	NS	NS	NS	NS	NS

* = P < 0.05; ** = P < 0.01; *** = P < 0.001
NS = Non Significant
P= Primary, S= Secondary, T= Tail, B= Breast, BK= Back

APPENDIX 6

Feed Intake, cystine intake and feed conversion ratio during 0-30 days of age (experiment 2)

Days	Diet	Cumulative Feed Intake (g/b/d)				Cumulative Cystine Intake (mg/b/d)				Feed Conversion Ratio (FCR) [1]			
		Fast		Slow		Fast		Slow		Fast		Slow	
		F	M	F	M	F	M	F	M	F	M	F	M
0	-	-	-	-	-	-	-	-	-	-	-	-	-
5	A	18.9	20.1	18.6	19.1	52.0	56.0	52.0	54.0	1.61	1.89	1.57	1.57
	B	17.9	19.4	18.4	18.8	58.0	62.0	58.0	60.0	1.50	1.88	1.52	1.62
	C	17.3	19.3	18.3	18.6	62.0	70.0	66.0	66.0	1.40	1.75	1.50	1.57
	D	18.6	18.7	18.1	18.2	74.0	74.0	72.0	72.0	1.66	1.64	1.54	1.54
	E	18.2	18.6	17.9	17.4	80.0	82.0	78.0	76.0	1.61	1.62	1.66	1.62
10	A	23.7	25.3	23.8	24.7	66.3	71.0	66.7	69.0	1.52	1.69	1.55	1.53
	B	22.5	24.2	23.3	23.7	71.7	77.3	76.7	75.7	1.44	1.54	1.48	1.48
	C	23.4	23.5	22.3	23.5	84.3	84.3	80.0	85.0	1.38	1.47	1.43	1.44
	D	23.6	24.3	21.4	25.0	94.7	97.3	85.0	99.7	1.49	1.41	1.38	1.52
	E	23.5	23.7	22.8	24.0	103.7	104.0	100.3	105.3	1.48	1.44	1.55	1.49
15	A	30.7	31.4	30.2	32.2	86.0	88.2	84.6	90.0	1.61	1.51	1.61	1.59
	B	29.3	31.1	29.8	31.6	93.8	99.3	95.6	101.3	1.50	1.43	1.57	1.57
	C	30.5	30.4	29.3	31.2	110.0	109.3	105.3	112.2	1.47	1.42	1.51	1.48
	D	30.3	31.2	27.4	32.5	121.5	124.7	109.5	130.0	1.55	1.45	1.46	1.55
	E	29.0	30.3	28.9	31.7	127.5	133.1	127.3	139.3	1.50	1.45	1.57	1.52
20	A	40.2	42.1	38.8	42.3	105.7	110.7	102.0	111.2	1.86	1.70	1.70	1.67
	B	39.1	41.1	38.9	42.2	116.7	122.7	116.3	125.8	1.72	1.58	1.67	1.64
	C	40.1	41.4	38.0	41.9	134.0	137.8	127.0	139.8	1.67	1.58	1.62	1.62
	D	39.0	41.4	36.3	43.2	146.5	154.7	135.8	161.5	1.70	1.58	1.61	1.67
	E	38.0	40.3	37.3	41.0	157.3	166.7	155.0	169.8	1.66	1.56	1.67	1.59
25	A	49.7	55.0	48.5	54.1	126.7	139.7	123.6	137.5	1.97	1.85	1.83	1.77
	B	48.8	53.6	48.9	53.7	140.5	154.0	141.1	154.4	1.85	1.74	1.82	1.75
	C	49.5	51.9	47.8	53.9	159.6	166.5	154.0	172.8	1.80	1.70	1.76	1.74
	D	47.9	52.9	46.8	54.7	173.9	190.9	168.8	197.6	1.83	1.73	1.76	1.76
	E	47.2	51.4	47.3	51.5	189.7	206.3	190.1	207.1	1.81	1.72	1.80	1.71
30	A	57.8	67.8	56.8	66.1	144.9	169.1	142.4	165.2	2.07	2.03	1.90	1.88
	B	56.8	63.6	57.3	65.3	160.6	179.3	162.0	184.2	1.91	1.82	1.89	1.81
	C	57.2	61.3	56.0	64.2	180.8	192.9	176.9	201.8	1.86	1.78	1.81	1.77
	D	55.6	62.5	55.4	64.2	198.0	222.0	196.6	228.0	1.90	1.82	1.85	1.77
	E	54.9	60.6	54.1	60.9	217.3	239.5	214.4	241.1	1.89	1.77	1.83	1.72

1) FCR = g feed/g body weight gain; F= Female, M= Male

(.....continued)

APPENDIX 6
(continued)

	Cumulative Feed Intake (g/b/d)	Cumulative Cystine Intake (mg/b/d)	FCR
MAIN EFFECTS			
Age - 5	66.2	18.5	1.61
10	84.9	23.6	1.49
15	109.4	30.5	1.52
20	134.9	40.1	1.65
25	164.7	50.8	1.79
30	190.8	59.9	1.85
SED	0.92	0.28	0.01
Diet - A	100.6	38.2	1.73
B	112.0	37.5	1.65
C	124.1	37.1	1.61
D	138.7	37.1	1.63
E	150.5	36.3	1.64
SED	0.84	0.26	0.01
Line - Fast	125.4	37.3	1.66
Slow	124.9	37.2	1.64
SED	0.53	0.16	0.01
Sex - Male	130.3	38.8	1.64
Female	120.0	35.6	1.66
SED	0.53	0.16	0.01
Significance of Difference:			
Age (A)	***	***	***
Diet (D)	***	***	***
Line (L)	NS	NS	***
Sex (S)	***	***	**
A x D	NS	***	NS
A x L	NS	NS	***
D x L	NS	NS	***
A x S	***	***	***
D x S	*	***	***
L x S	***	***	NS
A x D x L	NS	NS	NS
A x D x S	NS	NS	***
A x L x S	NS	*	***
D x L x S	*	**	***
A x D x L x S	NS	NS	NS

* = P < 0.05; ** = P < 0.01; *** = P < 0.001;
NS = Non Significant

APPENDIX 7

Body weight and body weight gain (experiment 2)

Days	Diet	Body Weight (gram)				Body Weight Gain (gram)			
		Fast		Slow		Fast		Slow	
		F	M	F	M	F	M	F	M
0	-	47.5	49.9	45.7	46.9	-	-	-	-
5	A	105.9	102.4	106.0	105.0	58.7	53.2	59.1	60.9
	B	108.7	102.4	104.8	105.8	60.1	51.7	60.6	58.2
	C	108.9	105.2	104.9	108.4	61.7	55.3	57.9	59.3
	D	104.8	107.7	103.1	105.8	56.4	57.0	58.7	59.0
	E	102.9	106.9	100.1	100.9	56.7	57.6	54.1	53.9
10	A	203.0	199.0	200.1	205.5	155.9	149.8	153.3	161.4
	B	207.4	208.0	201.4	208.1	156.9	157.3	157.3	160.5
	C	216.1	209.3	202.6	212.4	168.9	159.4	155.6	163.4
	D	207.3	222.6	199.0	211.3	158.9	171.9	154.7	163.9
	E	202.6	213.8	192.9	207.4	159.1	164.5	146.9	160.4
15	A	332.7	362.6	328.9	347.9	285.5	313.4	282.1	303.8
	B	342.8	370.0	329.8	350.7	292.3	319.3	285.6	303.2
	C	358.6	371.1	338.4	364.2	311.5	321.2	291.4	315.1
	D	342.1	372.6	325.6	360.7	293.6	321.9	281.3	313.9
	E	335.1	362.1	322.3	358.7	288.9	312.7	276.3	311.7
20	A	487.6	550.7	502.7	550.6	444.6	501.5	455.8	506.5
	B	506.3	572.2	510.9	562.9	455.8	521.5	466.7	515.3
	C	527.4	572.7	516.7	565.6	480.2	522.9	469.6	516.5
	D	506.9	575.9	499.6	565.6	458.5	525.2	455.3	518.8
	E	503.0	555.7	493.9	560.9	456.8	516.3	447.9	513.9
25	A	678.1	794.1	711.3	807.7	630.9	744.9	664.4	763.6
	B	709.0	819.4	718.0	816.4	658.5	768.7	673.8	768.9
	C	734.0	813.4	725.3	823.1	686.9	763.5	678.3	774.1
	D	703.4	813.2	709.6	821.0	654.9	762.6	665.3	774.2
	E	699.2	796.8	703.7	799.0	653.0	747.4	657.7	752.0
30	A	886.8	1048.7	943.4	1099.0	839.6	999.5	896.5	1054.9
	B	942.5	1100.1	954.4	1132.4	892.0	1049.4	910.3	1084.8
	C	968.8	1080.4	975.9	1133.9	921.6	1030.6	928.9	1084.9
	D	926.8	1079.8	945.0	1134.3	878.4	1029.2	900.7	1087.5
	E	917.5	1077.3	932.6	1112.0	871.3	1027.9	886.6	1065.0

F = Female, M = Male

APPENDIX 8

Primary and seconday wing feather lengths (experiment 2)

Days	Diet	Primary Feather Length (mm)				Secondary Feather Length (mm)			
		Fast		Slow		Fast		Slow	
		F	M	F	M	F	M	F	M
0	-	11.7	11.8	8.6	8.0	7.5	6.8	3.5	1.9
5	A	31.0	26.0	18.0	18.0	19.3	18.0	9.7	6.7
	B	31.0	26.7	18.0	18.0	19.0	18.0	10.0	6.7
	C	33.3	26.3	17.7	19.0	20.0	18.3	12.0	7.7
	D	33.7	27.7	18.7	19.0	19.7	18.3	11.0	8.0
	E	33.0	27.7	19.3	19.7	20.3	18.3	11.7	7.7
10	A	54.0	48.0	29.3	23.3	36.0	31.3	18.0	14.3
	B	54.7	49.3	29.3	25.0	37.0	31.3	19.3	14.3
	C	57.0	49.7	30.3	24.7	38.3	31.7	20.0	15.3
	D	58.0	51.0	29.7	24.7	39.7	32.7	20.3	15.3
	E	56.0	51.3	31.7	24.3	38.0	33.3	20.7	14.7
15	A	73.3	69.3	45.7	39.0	56.3	51.3	27.7	25.0
	B	74.7	72.0	46.7	40.3	58.7	51.7	30.3	25.0
	C	77.7	71.7	47.0	40.0	61.3	51.7	30.0	24.7
	D	77.7	73.7	46.7	41.3	61.3	53.3	32.3	27.0
	E	75.7	73.3	50.7	37.3	60.3	53.7	32.7	22.3
20	A	90.3	87.7	58.0	55.7	77.3	72.0	37.0	33.3
	B	89.7	89.7	64.0	58.7	76.7	72.3	43.7	35.3
	C	92.0	90.0	65.0	59.7	80.3	71.7	45.3	35.3
	D	92.0	91.3	68.0	61.3	80.7	75.0	50.7	38.7
	E	90.7	90.0	72.7	58.7	78.7	73.7	52.7	34.0
25	A	103.7	105.0	76.0	77.7	94.7	92.3	53.0	47.3
	B	104.3	105.7	83.0	79.7	95.3	92.3	62.0	50.0
	C	107.0	105.7	84.3	80.3	99.0	92.7	64.3	51.0
	D	105.3	108.0	87.0	81.3	98.7	96.0	69.3	54.3
	E	104.0	105.0	90.0	79.3	97.0	93.7	72.0	48.3
30	A	114.0	117.0	92.7	95.3	109.3	108.0	69.3	65.7
	B	114.0	118.7	100.0	99.3	111.0	109.3	81.0	69.0
	C	115.0	118.7	101.0	100.3	112.3	109.0	81.7	69.3
	D	114.7	120.3	102.3	101.7	111.0	112.0	86.7	71.0
	E	113.3	119.3	105.7	98.3	111.0	109.7	90.0	67.7

F = Female, M = Male

APPENDIX 9

Tail and back feather lengths (experiment 2)

Days	Diet	Tail Feather Length (mm)				Back Feather Length (mm)			
		Fast		Slow		Fast		Slow	
		F	M	F	M	F	M	F	M
5	A	3.3	0.0	0.0	0.0	-	-	-	-
	B	3.0	0.0	0.0	0.0	-	-	-	-
	C	4.0	1.0	0.0	0.0	-	-	-	-
	D	4.3	1.3	0.0	0.0	-	-	-	-
	E	5.3	0.3	0.0	0.0	-	-	-	-
10	A	14.0	8.0	2.0	0.0	2.3	0.0	0.0	0.0
	B	14.3	7.7	2.7	0.0	2.3	0.0	0.0	0.0
	C	15.7	9.0	2.3	0.0	2.3	0.0	0.0	0.0
	D	16.0	10.3	2.0	0.0	2.3	0.3	0.0	0.0
	E	16.7	9.7	3.3	0.0	3.3	0.7	0.0	0.0
15	A	28.7	17.7	10.7	7.3	10.7	7.7	3.7	0.3
	B	28.7	18.0	10.7	7.0	11.0	8.0	4.3	1.0
	C	30.7	19.0	11.0	7.3	11.0	8.7	4.3	1.0
	D	32.3	21.7	11.0	7.0	12.0	8.7	4.3	1.7
	E	31.7	19.3	12.0	7.7	11.3	9.0	4.7	1.7
20	A	43.0	29.0	17.0	12.0	17.3	14.3	7.7	4.7
	B	43.3	29.3	19.3	11.7	17.7	14.7	9.0	4.7
	C	48.7	32.0	20.0	12.7	19.3	14.7	9.3	5.7
	D	50.0	34.7	19.7	12.7	19.3	15.7	10.3	5.7
	E	48.7	31.3	22.7	13.3	19.0	16.7	11.3	6.3
25	A	62.0	42.3	25.3	18.3	29.0	24.3	15.0	10.7
	B	62.7	42.7	29.0	18.7	29.0	25.0	16.7	11.7
	C	69.0	46.0	30.0	18.7	29.7	25.7	17.7	11.7
	D	70.0	48.3	29.7	20.0	29.7	26.0	18.7	11.7
	E	67.7	45.3	33.3	19.7	29.0	26.7	21.0	12.0
30	A	79.3	57.0	35.7	26.3	38.0	36.0	22.7	18.7
	B	80.7	57.0	42.3	27.0	38.3	36.0	27.0	19.3
	C	86.3	63.3	42.0	28.0	39.7	35.7	28.0	19.0
	D	89.0	64.3	42.0	27.7	39.7	36.7	28.7	21.0
	E	86.3	62.0	46.3	27.7	38.7	37.3	31.0	20.7

F = Female, M = Male

APPENDIX 10

Breast and thigh feather lengths (experiment 2)

Days	Diet	Breast Feather Length (mm)				Thigh Feather Length (mm)			
		Fast		Slow		Fast		Slow	
		F	M	F	M	F	M	F	M
5	A	-	-	-	-	-	-	-	-
	B	-	-	-	-	-	-	-	-
	C	-	-	-	-	-	-	-	-
	D	-	-	-	-	-	-	-	-
	E	-	-	-	-	-	-	-	-
10	A	5.7	2.3	0.3	0.0	10.7	9.0	2.3	0.7
	B	5.7	2.3	0.7	0.0	10.7	9.0	2.0	0.7
	C	5.7	2.3	0.7	0.0	11.3	9.0	2.0	1.0
	D	6.3	3.7	1.0	0.0	12.0	9.3	3.0	0.3
	E	6.3	3.7	0.7	0.0	12.0	10.0	3.3	0.3
15	A	16.0	12.3	7.0	4.7	23.0	19.3	9.3	7.0
	B	15.7	12.0	7.0	3.7	23.0	19.7	9.0	6.7
	C	16.0	13.0	6.7	4.0	24.3	20.3	9.3	7.0
	D	17.0	13.3	7.0	3.7	24.3	21.3	9.7	6.0
	E	15.3	13.0	7.0	4.0	23.7	22.0	11.0	6.0
20	A	25.7	22.3	13.3	11.3	33.0	29.3	15.3	14.0
	B	25.7	22.0	15.0	10.3	33.3	29.7	17.3	14.3
	C	26.7	23.3	15.7	10.3	34.3	29.7	18.7	14.0
	D	26.7	24.0	16.7	10.7	34.0	32.0	19.7	14.0
	E	26.3	23.0	19.0	10.7	34.7	32.0	21.7	15.3
25	A	37.0	33.7	24.7	22.7	45.0	41.0	23.3	22.3
	B	36.7	34.7	26.7	21.0	44.7	40.7	26.3	22.7
	C	38.0	35.0	26.7	20.0	47.0	41.7	27.0	22.7
	D	38.7	36.7	28.7	21.7	48.0	43.7	28.7	22.7
	E	36.7	35.0	30.3	22.3	47.3	44.0	32.0	24.0
30	A	45.0	44.3	34.3	32.0	57.3	54.3	33.7	32.3
	B	47.3	45.0	37.0	32.3	57.0	53.7	38.7	33.3
	C	47.3	44.7	36.7	32.0	59.3	54.0	38.7	33.7
	D	47.0	46.7	38.7	32.3	60.7	57.3	41.3	33.0
	E	46.7	45.0	41.3	33.7	58.3	57.0	45.3	34.0

F = Female, M = Male

APPENDIX 11

Mean of body weight and feather lengths (Appendices 7-10)

		BW	BWG	P	Feather Lengths (mm) S	T	BK	B	TH
MAIN EFFECTS									
Age -	0	47.5	-	10.1	4.9	0.0	0.0	0.0	0.0
	5	105.2	57.7	24.1	14.0	1.1	0.0	0.0	0.0
	10	206.5	159.0	40.1	26.1	6.7	0.7	2.4	5.9
	15	348.8	301.2	58.7	41.8	17.0	6.3	9.9	15.1
	20	534.4	487.5	76.3	58.2	27.6	12.2	18.9	24.3
	25	759.8	712.2	93.6	76.2	39.9	21.0	30.3	34.7
	30	1019.6	972.0	108.1	92.7	53.5	30.6	40.5	46.7
SED		3.21	3.45	0.45	0.55	0.45	0.23	0.26	0.33
Diet -	A	423.1	439.2	56.6	42.5	19.3	9.4	14.1	17.2
	B	434.8	451.2	58.3	44.2	19.9	9.8	14.3	17.6
	C	440.5	457.6	59.1	45.1	21.3	10.1	14.5	18.0
	D	433.4	450.1	59.9	46.6	21.9	10.4	15.0	18.6
	E	426.6	443.3	59.6	45.8	21.8	10.7	15.0	19.1
SED		2.71	3.15	0.38	0.46	0.38	0.20	0.22	0.28
Line-Fast		430.4	445.4	68.6	56.9	29.5	13.3	17.9	23.7
Slow		433.0	451.1	48.8	32.8	12.2	6.9	11.2	12.5
SED		1.71	1.99	0.24	0.29	0.24	0.13	0.14	0.18
Significance of Differences:									
Age (A)		***	***	***	***	***	***	***	***
Diet (D)		***	***	***	***	***	***	***	***
Line (L)		***	NS	***	***	***	***	***	***
Sex (S)		***	***	***	***	***	***	***	***
AxD		*	NS	NS	*	***	*	NS	**
AxL		***	***	***	***	***	***	***	***
DxL		NS	*	**	**	***	NS	*	NS
AxS		***	***	***	***	***	***	***	***
DxS		NS	**	**	***	*	NS	NS	*
LxS		NS	*	***	***	***	***	***	***
AxDxL		NS	NS	*	NS	NS	NS	NS	NS
AxDxS		NS	NS	NS	NS	NS	NS	NS	NS
AxLxS		NS	NS	***	***	***	***	***	NS
DxLxS		NS	NS	***	***	NS	*	**	***
AxDxLxS		NS	NS	NS	NS	NS	NS	NS	NS

* = P < 0.05; ** = P < 0.01; *** = P < 0.001;
NS = Non Significant
BW= Body Weight, BWG= Body Weight Gain, P= Primary,
S= Secondary, T= Tail, BK= Back, B= Breast, TH= Thigh

APPENDIX 12

Feeding programme of broiler breeder

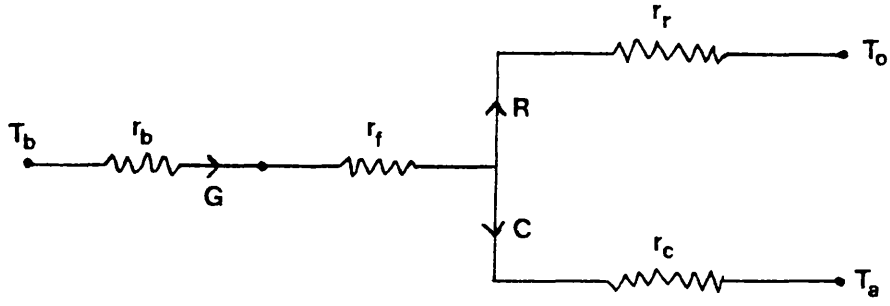
Ration	Age		Feed	
	Weeks	Days	(g/bird/day)	
Starter	1	0- 7	ad-lib	
	2	8-14	ad-lib	
	3	15-21	ad-lib	
	4	22-28	ad-lib	
	5	29-35	52	
	6	36-42	57	
Grower	7	43-49	60	
	8	50-56	ad-lib	
	9	57-63	ad-lib	
	10	64-70	ad-lib	
	11	71-77	73	
	12	78-84	76	
	13	85-91	77	
	14	92-98	80	
	15	99-105	82	
Grower			Female	Male
	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 %			
	5		140	then
	35		150	increased
	70		160	to 140

APPENDIX 13

Theory of thermal resistance of feathers

(C.M.Wathes, Bristol University, personal communication)

Assume a simple resistance analogue of heat losses from an animal to the environment. The diagram below shows four resistances to heat flow of which r_f is the resistance of the feathers.



At equilibrium $G = C + R$ (W/m^2)

where G is the total sensible heat flux, C is the convective heat loss and R is the radiant heat loss. Alternatively

$$\frac{\rho C_p (T_b - T_s)}{r_b} = \frac{\rho C_p (T_s - T_f)}{r_f} = \frac{\rho C_p (T_f - T_o)}{r_r} + \frac{\rho C_p (T_f - T_a)}{r_c}$$

where ρ = density of air (kg/m^3)

C_p = specific heat of air ($J/kg/^oC$)

T = temperature (^oC)
- b - body or core
- s - skin
- f - feathers
- o - radiative temperature of surroundings
- a - dry air

r = thermal resistance (s/cm)
- b - body, including tissue and fat
- f - feathers
- r - equivalent radiation resistance
- c - convection (boundary-layer)

(.....continued)

Rearranging we have

$$r_f = \left[\frac{(T_f - T_o)}{r_r} + \frac{(T_f - T_a)}{r_c} \right]^{-1} \times (T_s - T_f)$$

Therefore, by measuring T_f, T_o (with a radiometer), T_a and T_s, thermal resistance r_f can be calculated for each bird assuming constant values for r_r and r_c.

r_c depends on the size of the bird and whether the convective heat losses occur by forced or natural convection. However, if air speeds around the bird are in the range 0.1 to o.2 m/s then a value of 3.7 s/cm will suffice for an adult hen. r_r depends on T_f and T_o but 2.3 s/cm is a good estimate at normal room temperatures.

ρC_p = 1200 J/m^3/^{o}C

APPENDIX 14

Effects of age, line and sex on physiological variables (experiment 7, in the climate room)

Line/ Sex	Age (Days)	Rectal Temperature °C	Back Skin Temperature °C	Feather Surface Temperature °C	Surrounding Temperature °C	Ambient Temperature °C	Thermal Resistance of feathers (r_f) s/cm
FF	17	41.0	39.3	31.0	19.0	23.5	1.17
	24	41.1	39.3	29.0	20.0	24.0	1.95
	31	42.0	39.7	26.8	20.0	24.1	3.59
	38	41.1	39.3	25.0	19.0	24.0	4.96
	45	41.5	39.4	25.0	20.0	24.3	6.09
FM	17	41.0	39.0	31.3	19.0	23.5	1.07
	24	40.8	39.0	30.0	20.0	24.0	1.53
	31	41.5	39.3	25.8	20.0	24.1	4.81
	38	41.1	39.5	25.3	19.0	24.0	4.71
	45	41.4	39.4	25.0	20.0	24.3	6.09
CF	17	40.9	39.0	31.5	19.0	23.5	1.01
	24	41.0	39.4	30.6	20.0	24.0	1.39
	31	41.3	39.5	26.8	20.0	24.1	3.72
	38	41.2	39.4	25.3	19.0	24.0	4.81
	45	41.4	39.4	25.5	20.0	24.3	5.23
CM	17	41.0	38.7	31.4	19.0	23.5	0.99
	24	40.9	38.9	32.3	20.0	24.0	0.94
	31	41.0	39.0	30.5	20.0	24.1	1.38
	38	41.1	39.1	26.8	19.0	24.0	3.11
	45	41.6	39.6	27.3	20.0	24.3	3.09
SF	17	40.8	38.5	31.5	19.0	23.5	0.93
	24	41.1	38.6	33.9	20.0	24.0	0.56
	31	41.0	38.8	31.3	20.0	24.1	1.26
	38	40.9	39.1	28.6	19.0	24.0	2.38
	45	41.3	39.2	29.0	20.0	24.3	2.33
SM	17	40.7	38.5	31.4	19.0	23.5	0.96
	24	40.9	38.6	33.5	20.0	24.0	0.61
	31	41.1	38.7	34.5	20.0	24.1	0.48
	38	41.1	38.9	31.4	19.0	24.0	1.13
	45	41.4	39.3	29.5	20.0	24.3	1.86
SED		0.13	0.17	0.63	-	-	0.32

FF= Fast Female, FM= Fast Male, CF= Control Female, CM= Control Male, SF= Slow Female, SM= Slow Male

(.....continued)

APPENDIX 14
(continued)

	Temperature (°C) Rectal	Back Skin	Feather Surface	r_f s/cm
MAIN EFFECTS				
Age - 17	40.9	38.8	31.3	1.02
24	41.0	39.0	31.6	1.16
31	41.3	39.1	29.3	2.54
38	41.1	39.2	27.0	3.52
45	41.4	39.4	26.9	4.11
SED	0.05	0.07	0.26	0.13
Line - Fast	41.2	39.3	27.4	3.60
Control	41.2	39.2	28.8	2.57
Slow	41.0	38.8	31.5	1.25
SED	0.04	0.06	0.20	0.10
Sex - Male	41.1	39.0	29.7	2.18
Female	41.2	39.2	28.7	2.76
SED	0.03	0.05	0.16	0.08
Significance of Differences:				
Age (A)	***	***	***	***
Line (L)	***	***	***	***
Sex (S)	NS	***	***	***
A x L	***	*	***	***
A x S	*	*	**	***
L x S	*	NS	***	***
A x L x S	NS	NS	***	***

* = P < 0.05; ** = P < 0.01; *** = P < 0.001
NS = Non Significant

APPENDIX 15

Effects of age, line and sex on feather length and back feather score (experiment 7, in the climate room)

Line/ Sex	Age (day)	Feather Lengths (mm) Primary	Secondary	Tail	Back	Back Score
FF	17	81	67	36	12	2
	24	99	86	49	24	5
	31	114	108	81	36	6
	38	119	122	104	45	6
	45	131	130	119	53	6
FM	17	75	57	24	9	2
	24	99	85	41	21	4
	31	115	107	60	34	6
	38	124	123	79	42	6
	45	134	137	104	48	6
CF	17	74	54	19	8	2
	24	97	84	40	20	4
	31	112	101	57	31	6
	38	122	118	71	39	6
	45	131	131	101	51	6
CM	17	71	48	10	2	1
	24	95	70	22	15	3
	31	115	99	31	23	5
	38	126	114	45	37	6
	45	141	133	59	51	6
SF	17	27	10	5	0	1
	24	73	47	16	9	2
	31	86	61	30	19	4
	38	103	85	39	31	5
	45	120	99	54	39	5
SM	17	32	8	3	0	1
	24	45	16	9	4	2
	31	78	36	12	10	2
	38	101	71	22	25	4
	45	122	94	33	34	5
SED		4.90	6.73	6.07	2.43	0.31

FF= Fast Female, FM= Fast Male, CF= Control Female, CM= Control Male, SF= Slow Female, SM= Slow Male

(.....continued)

APPENDIX 15
(continued)

	Feather Lengths (mm)				Back
	Primary	Secondary	Tail	Back	Score
MAIN EFFECTS					
Age - 17	60.0	42.4	16.0	5.4	1.56
24	84.5	64.5	29.2	15.2	3.33
31	103.4	85.2	45.2	25.4	4.67
38	115.7	105.4	59.9	36.7	5.33
45	129.7	120.8	78.4	45.9	5.61
SED	2.00	2.75	2.48	0.99	0.13
Line - Fast	109.1	102.1	69.7	32.4	4.94
Control	108.3	95.2	45.2	27.7	4.35
Slow	78.6	53.7	22.2	17.1	3.02
SED	1.55	2.13	1.92	0.77	0.10
Sex - Male	98.1	80.4	36.9	23.7	3.80
Female	99.2	86.9	54.6	27.7	4.40
SED	1.27	1.74	1.57	0.63	0.08
Significance of Differences:					
Age (A)	***	***	***	***	***
Line (L)	***	***	***	***	***
Sex (S)	NS	***	***	***	***
A x L	***	*	***	***	***
A x S	**	*	***	NS	**
L x S	*	*	*	NS	*
A x L x S	**	*	NS	NS	*

* = P < 0.05; ** = P < 0.01; *** = P < 0.001;
NS = Non Significant