Evaluation of techniques for improving broiler performance during the first week of life

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THESIS

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Declaration

These studies have not been submitted in any other form to another university and, except where the work of others is acknowledged in the text, are the result of my own investigation.

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T. P. Mabusela R. M. Gous

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Dedication

This thesis is dedicated to my late grandmother, Hombakazi Adelaide Mabusela.

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I would like to express my sincere thanks to the following institutions and people for their invaluable contribution to the work presented in this dissertation:

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Abstract

The overall objective of this study was to evaluate the interventions that may be used to improve broiler performance during the first week of the life of a broiler chicken. Four experiments were conducted on caged broiler chickens. The interventions applied included the use of feeds varying in dietary protein contents, the use of pelleted *vs*. mash feed and the use of various feed additives, including additional vitamins and trace minerals, brewers yeast, Spirulina, conjugated linoleic acid (CLA) and an enzyme cocktail supplied by Optivite. In addition, access to feed was identified as a potential problem in the cages used in these trials, so feed trough position was tested, these being positioned either inside or outside the cages. The performance variables measured included growth rate, food intake and food conversion efficiency (FCE), the main objective being to maximise body weight at 7d. In all four experiments, broiler chickens showed a significant improvement in all variables when dietary protein content was increased, when pelleted feed was used, and when the feed was positioned inside the cage. No improvements occurred as a result of the addition of any of the feed additives except the enzyme cocktail from Optivite, which improved performance significantly. The best mean performance recorded over all the trials was on the highest protein feed (221g/kg) containing Optivite, when the feed was pelleted through a 1.8mm die and fed inside the cage, the body weight of the chicks at 7d being 157 g, having consumed 164 g feed/chick at an FCE of 957 g/kg.

General Introduction

The poultry industry is one of the largest agricultural businesses in the world. Like any other agricultural business, its ultimate goal is to generate profit. In the poultry industry, feeding chickens is the single largest expenditure, which comprises 70 to 80% of the total expenditure. Since feed is so expensive, producers have a vested interest in perfecting the production line of their chickens, thereby improving feed utilisation. These chickens have been genetically modified and bred for maximum growth and meat yield, and precision feed programs have been developed and are constantly being upgraded to make utmost use of the genetic enhancement.

To keep up with the improvements made both by geneticists and nutritionists, it has become essential that chickens perform to their potential at each stage of growth. Hence, getting broilers off to a good start has become an important factor in any broiler operation. Experience and knowledge passed on by researchers has shown that extra care must be taken in the first week, to keep broiler chickens on track in terms of growth, efficiency, and overall health. It is vital that young broiler chickens be encouraged to consume adequate amounts of food immediately after placement, and that studies on methods of improving their consumption be conducted.

Although the importance of maximising food consumption during the first week is clear and understood by broiler producers, poor food consumption is often observed and given as reason for poor performance of broiler chickens. This results in an increasing need to identify and eliminate constraints to food intake and overall performance.

Since the first week of life is of utmost importance in a broiler production system, researchers have recently devoted considerable amounts of time in studying ways in which food consumption and growth rate can be maximized during this period. Feeds varying in nutritional properties are currently being researched to determine the feed with the best overall effect on growth and liveability. Thus, a special pre-starter diet is now often recommended for the first week, which needs to be formulated according to the nutritional requirements of the young broiler chicken at this stage. Because so little of this feed is consumed during this period of growth compared with the amounts consumed later, it is possible to use high quality ingredients, use higher nutrient contents than would be economically worthwhile if greater amounts were being consumed, and it is worth spending money producing a good quality pellet, using a special 1.8 or 2.0mm diameter die.

A pre-starter feed can be formulated to contain higher dietary amino acids than would be economically viable in a starter feed being fed to, say, three weeks of age. The latest broiler genotypes respond better to higher amino acid contents than did broiler chicks of the past, as they have a greater potential to grow but cannot consume large amounts of food. These required dietary concentrations decrease rapidly as the birds grow and food intake increases, so they need only be fed like this for a short time.

Mini-pellets, of between 1.5 and 1.8mm diameter, have been shown to improve food conversion efficiency, by reducing maintenance requirements. There is also some evidence that growth rate is improved when these mini-pellets are used in place of crumbles or mash. Two experiments were designed to investigate the effect of feeding different feed forms to young broiler chickens.

The physiology of broiler chickens during the first week of life is different from that of older broilers, as their ability to absorb certain nutrients has not yet been fully developed (Noy and Sklan, 1995). Therefore, it has been recommended that a special, pre-starter diet be used for broilers during the first week of life (Penz, 2002). This could be formulated to contain low levels of dietary fat; high sodium levels and with the addition of feed additives (Penz, 2002).

The main objective of this dissertation is to look at the ways of maximizing food intake and weight gains during the first week of life. This will be pursued by concentrating on the feed compositions and form as tools for maximising broiler performance.

Chapter 1

Literature review

1.1 Introduction

Growth rate of broiler chickens has improved considerably over the years, resulting in an earlier marketing age. This trend continues and emphasizes the importance of growth during the pre-starter period (first week after hatching), which now constitutes about 18% of the life span of broiler chickens commercially harvested at 38d of age. For broiler chickens to be able to reach their genetic potential at 38d of age, the nutritional and environmental conditions immediately after hatching must be such that the broiler chickens will be encouraged to consume adequate amounts of food, that food will be readily digested by the chickens, and that the environment will not place any constraint on the growth or feed intake of these chickens.

The physiology of broiler chickens during the first week of life is different from that of older broilers, as their ability to absorb certain nutrients has not yet been fully developed (Noy and Sklan, 1995). Therefore, it has been recommended that a special, pre-starter diet be used for broilers during the first week of life (Penz, 2002).

Remarkable physiological changes of the digestive tract occur during the first week after hatching, with 90% of the intestinal growth taking place during the first 5 d of life (Noy and Sklan, 1995), which allows an increase in food intake and modifies nutrient digestibility (Penz, 2002). The young broiler chicken depends on its yolk sac for nutrients both before hatching and for a limited period after hatching, but stimulus of solid food promotes the main changes in the physical structure of the digestive system and its secretions, essential for the digestion of nutrients (Noy and Sklan, 1995). It is therefore important that young broiler chickens have access to food as soon as possible after hatching. Leaving the young broiler chickens without food delays the stimulus of the nutrients on the development of the digestive system and reduces the use of available nutrients in the yolk sac. However, young broiler chickens usually do not have access to food during the first 24 to 36 h after hatching, as this is the time used for sexing and vaccination. Many broiler chickens hatch out 24 h or more before being removed from the hatchery compartment, and will be without food during this time and will start losing weight. The consequence of this delay prior to accessing food reduces performance later in their lives, as any gain that broiler chickens get early on in their lives, as a result of early feeding immediately after clearing the shell, is maintained until marketing age (Noy and Sklan, 1995).

Although it is of utmost importance to ensure that broilers grow to their potential during the first week of life, researchers have largely neglected the nutritional requirements of broiler chickens during this period. Many studies have been conducted on the nutritional requirements of broilers, but in general these studies have commenced from 7 d of age, or the overall performance for the first 2 or 3 weeks of life has been reported. This has led to insufficient information being available about the nutritional requirements of broilers during the first week of life.

Penz (2002) suggested a number of interventions that may result in improved first week weights. These include the feeding of feeds high in amino acid content, providing environmental temperatures lower than the conventional temperatures used, increased dietary sodium levels, pelleted as opposed to mash feeds, the use of relatively coarse grain particle size, the use of betaine and the use of feed additives such as growth promoters.

The above interventions have been reviewed in this document in an attempt to identify the most important factors influencing 7 d body weights in commercial broiler chickens.

1.2 Nutritional requirements

The primary objective of every broiler operation is to maximise profitability of the enterprise. Therefore, it is important that broiler chickens be fed in a way that will enable them to achieve their growth potential. Chickens require certain intakes of nutrients to be able to achieve their maximum level of production. According to Emmans and Fisher (1986) animals eat to satisfy their requirement for the first limiting nutrient in the feed. These authors went on to say that if chickens are fed unbalanced feeds they will over consume nutrients in an attempt to obtain the required level of the limiting nutrient, and that productivity of the chickens will be determined by the intake of the nutrient that is first limiting in the feed.

The nutritional requirements under consideration here are energy and protein. These nutrients interact to affect the potential tissue deposition of the animal (Morris *et al.*, 1999).

1.2.1 Amino acid requirements

The amino acid requirements of a growing chicken are governed by the demand for maintenance, growth of feathers and body protein (Freeman, 1979). These constitute the daily requirement of each amino acid that needs to be supplied in a feed. Young chickens require more amino acids than older chickens, as they are still forming new cells which are mostly protein and because of their fast growth. Amino acid requirements are influenced by a number of factors, which include the size of chicken at hatch, sex and genetic potential (Peisker, 1999).

Chicken size at hatch

Hatchling size is governed by the age of the maternal flock (Noy and Sklan, 1997), and is positively correlated to the egg size (Wilson, 1991). Chickens from bigger eggs are bigger with a higher maintenance and growth potential than those from small eggs (Pinchasov, 1991). Therefore, it is expected that bigger chickens will perform better than small chickens. Smaller chickens require higher dietary amino acid concentration than bigger chickens (Shanawany, 1987). This is due to the limited food intake that they can achieve, so for them to get the required amino acid content the dietary amino acid concentrations should be high. Noy and Sklan (1995) concluded that the advantage gained by an increase in size of chickens at hatch is kept until marketing age. However, Pinchasov (1991) observed that this advantage diminishes after 18 d of age.

Genetics

Genetic selection has played an important role in improving growth of broiler chickens. This has been achieved by an alteration of genotype. Broiler producers often believe that these improved strains would show higher food intake that should compensate for dietary amino acid supply lower than required, but Morris and Njuru (1990) found that this is not the case.

Amino acid requirements of these improved genotypes need to be predicted and feeds formulated according to the predicted values (Peisker, 1999). Potential growth rate of different strains must be taken into account when formulating these feeds, as different chickens have different genetic potential, hence they will respond differently to different formulations. Cahaner *et al.* (1987) reported a relationship between dietary protein content and the genotype. Hulan *et al.* (1980) found that genotype had an effect on food conversion efficiency. This could be due to decreased food intake for the same gain or increased body weight for the same amount of food consumed, or the combination of these two mechanisms.

Sex

Penz (2002) stated that with modern broiler chickens it is necessary to formulate feeds according to sex, as males and females differ in their amino acid requirements. This is in accordance with Peisker (1999) who concluded that males have higher amino acid requirements than females because of their higher genetic potential for lean tissue growth. Feeding both sexes feeds that are formulated according to the requirements for females results in undersupply of amino acids required by males and *vice versa*. By oversupplying amino acids to females, they will catabolise the excess amino acids and the unutilised energy will be converted to fat. Hunchar and Thomas (1976) found that males have higher requirements for arginine and tryptophan than females while Han and Baker (1993) found higher requirements for lysine by males.

Baker and Han (1994) stated that it is the faster growth rate and higher protein tissue accretion that results in higher amino acid requirements of male broiler chickens. Consequently, in order to determine the amino acid requirements of males and females, an accurate description of their potential growth and fatness is needed.

1.2.2 Factors affecting food intake

The amount of food consumed by a chicken is determined by it's genetic potential, the quality of food on offer and the environment, especially the environmental temperature (Emmans and Oldham, 1988).

Genetic potential varies between chickens, with some chickens having the potential to consume more food than others. The quantity of food that a young chicken can consume is limited by the gut length and surface area (Pinchasov and Noy, 1993). According to these authors if chickens are fed an unbalanced diet, the amount of food consumed will be limited by size of their gut.

It has also been suggested that the quality of food affects the amount of food that the chicken will consume (Emmans and Oldham, 1988). According to these authors these include: the palatability, bulkiness and nutrient composition of the food.

There is a general consensus among researchers on the adverse effect of extremely high temperatures on food intake. This will be dealt with in detail later.

The latest genotypes need to consume more amino acids each day than was the case in the past. A number of interventions have been proposed to accomplish this: which include increasing dietary amino acid contents and other nutrients, coarse grain particle size, pelleted feed as opposed to mash feed, use of high dietary sodium levels, need for addition of food additives and low environmental temperatures. These will be discussed in detail in subsequent sections.

1.2.2.1 Amino acid balance

Models play an important role in predicting the requirements of the broiler chicken at different stages of growth and under different environmental conditions in which they are reared. The graded supplementation is the method favoured by commercial nutritionists to predict the intake of amino acids that need to be supplied to broiler chickens based on their age, their growth potential or their body size. The experiments conducted using this method give the intake required, but to formulate a feed a concentration is needed, that is, intakes need to be predicted. If one gets this wrong then an oversupply or undersupply of nutrients occurs.

Broiler chickens have certain requirement for each amino acid for their growth and body functioning. Therefore, it is important that each amino acid is supplied at the level that will allow optimum performance, that is, broiler chickens are fed well-balanced feeds, as some imbalances are tolerated, whereas others cause severe problems.

There is antagonism that exists between two amino acids that are closely related (Peisker, 1999), for example, lysine and arginine, which have an adverse effect on amino acid utilisation and food consumption. Some amino acids when fed in excess of their requirement cause a toxicity that has an adverse effect on food intake and growth (Emmans and Fisher, 1986), but this is not the case with all amino acids.

Given the potential growth rate of a broiler chickens it is possible to predict (calculate) the amino acid intake that will allow them to attain their potential growth rate at different stages of growth. By specifying an energy content and assuming that the broiler chicken will consume first sufficient of the food to meet its energy requirement, it is possible to predict a food intake for each day of the growing period. Given this food intake and the amino acid intakes required it is possible then to calculate the amino acid content of the feed on each day of the growing period (Table 1.1).

Commercial nutritionists would not necessarily make use of these amino acid values because of the cost implications and/or the stability of the different feed ingredients to supply a balanced mixture. The optimum economic amino acid supply must be determined by optimisation techniques.

Table 1.1 *Digestible Amino acid requirements (%) of broilers of different age groups. (EFG broiler growth model, Emmans et al., 2002)*

Age	lys	met	tsaa	trp	ile	his	arg	thr	p+t	leu	val
7	1.51	0.50	0.85	0.21	0.86	0.53	1.46	0.91	1.57	1.52	0.97
14	1.37	0.46	0.80	0.19	0.80	0.48	1.35	0.84	1.47	1.41	0.91
21	1.24	0.41	0.76	0.18	0.74	0.43	1.24	0.78	1.36	1.30	0.85
28	1.14	0.38	0.72	0.16	0.69	0.40	1.16	0.72	1.28	1.21	0.79
35	1.05	0.35	0.68	0.15	0.64	0.37	1.08	0.68	1.19	1.13	0.74

1.2.2.2 Effect of dietary energy to protein ratio on broiler performance

The productivity of poultry is partly regulated by the energy to protein ratio of the feed, through changes in food intake, absorption of key nutrients and metabolism of amino acids required for protein accretion (Bartov, 1995). There is a minimum amount of energy that is required for protein to be properly utilised. However, commercial poultry nutritionists tend to feed feeds that do not meet this requirement (R. M. Gous, 2002, personal communication). Therefore, they tend to offer feeds that are unbalanced in terms of dietary energy and protein. These feeds tend to contain less metabolisable energy than is required. They may be doing this because chickens often do not respond to utilisation of high dietary amino acids, which is a costly exercise.

Although broiler production is concerned primarily with the production of high liveweight gain, with less food consumption, the production of lean tissue, the component of body weight gain in broiler chickens of most commercial value (Wiseman, 1986) has become of importance. There has been an increased demand for lean meat by poultry meat consumers that may have led to the increased need for lean tissue production. Lean tissue is primarily muscle protein and its production is an energy demanding process (Wiseman, 1986), which means it may not occur if adequate dietary energy is not supplied.

The consequence of feeding chickens feeds that have high energy values but lower in dietary amino acid is that chickens will consume excess energy in an attempt to get the required level of amino acids, resulting in increased carcass fat deposition (Wiseman, 1986).

There has been a contradicting literature about effect of feeding young broiler chickens feeds that contain high dietary amino acids during the latter stages of growth, with Kubena *et al.* (1974) concluding that this practice results in excessive carcass fat in the later growth stages. In contrast, Griffiths *et al.* (1977) found no increased fat deposition as a result of increasing dietary amino acid early in the chicken's life. Wiseman (1986) conducted an experiment to verify which of the previous findings was correct. This author did this by utilising three dietary energy levels (10.8, 12.8 and 14.8 MJ/kg) at constant dietary protein level (230g/kg). This author found that body weight gain, food intake and food conversion efficiency may be influenced considerably by increased energy to protein ratio, and the high energy to protein ratio was associated with heavier chickens with better efficiencies. However, the higher dietary energy to protein ratio resulted to broiler chickens that were overfat (Wiseman, 1986).

Since the primary objective of production has become the production of lean tissue, the results that occur because of high dietary energy to protein ratio have become undesirable, as the resulting broiler chickens are overfat (Wiseman, 1986). This demonstrated the importance of increasing dietary protein above optimum at constant energy. This practice results in broiler chickens that are leaner, as excess protein has to be catabolised, which is an energy demanding process, thus reducing energy that will be available for growth.

Bartov (1995) studied the effect of age of the broiler chicken offered feeds containing high protein with low energy and low protein with high energy. This author found that broiler chickens that were fed high protein with low energy feed consumed less food than those offered low protein with high energy feed. He claimed that weight gain was not influenced by the feed during the early growth stage (6 to 14d), but for 6 to 21 d chicks receiving high protein-low energy feed gained significantly more weight. Food conversion was constantly better for the low protein-high energy feed.

Gous *et al.* (1990) found increased fat deposition as a result of reducing dietary protein and by diluting the feed with oil or starch. These authors also found a reduction in fat deposition when the feed was diluted with dietary fibre.

The energy: protein ratio it an important component of the feed that needs to be strictly maintained when formulating feeds in order to yield the desired quality of the product (meat).

1.3 Maize particle size and its effect on performance

Several studies have explored the effect of maize particle size on performance of broiler chickens with variable results (Reece *et al.*, 1986a,b; Douglas *et al.*, 1990; Nir *et al.*, 1990, 1994; Lott *et al.*, 1992). The reasons for variation in performance caused by particle size are not completely understood. Savory (1974) stated that the size and consistency of feed particles affect the sensory input that normally accompanies feeding behaviour; and that the improved performance due to feed texture could be attributed to more effective food utilisation and to a some extent to higher food intake. In most studies physical attributes of the feeds such as particle size, as described by geometric mean diameter (GMD), and the variation in particle size (as described by geometric standard deviation (GSD)), are not reported. However, these attributes seem to affect food intake and performance.

Traditional nutrition texts seem to indicate that grains need to be ground in order to maximise broiler chicken performance and growth. The correct particle size required for broiler chicken feeds has been subject to debate among nutritionists who state that particle size should be established by means of GMD and complete information on particle size should include a measure of dispersion. This measure is the GSD, which establishes the range of variation among the different sized particles (Reece, 1986b).

According to Nir *et al.* (1994b) particle size must not be evaluated only on GMD basis; it must also include GSD, which must be kept at as low a rate as possible for better performance.

Nir *et al.* (1994a) demanded recognition of the fact that nutrient digestibility decreases when small particles are used because they cause gizzard atrophy and discrete intestinal hypertrophy caused by bacterial fermentation. Nir *et al.* (1995) reported that particle breakdown in the small intestine is slower when particles are large. This causes an increase in peristalsis, leading to a better nutrient utilisation.

Nir *et al.* (1994b) worked with broiler chicken feeds based on corn, sorghum or wheat processed by using roller mill, and divided the particles into small (GMD of 0.57and 0.67mm), medium (GMD of 1.13 and 1.23mm) and coarse (GMD of 2.01 and 2.10mm) particles. They found that for the period of 1 to 21 d of age, broiler chickens offered fine particles, independent of the grain used, had lower food intake, weight gain and worse food conversion efficiency (Table 1.2). Confirming the preference of broilers for large particle consumption, Penz (2002) cited Klein (1996) that worked with pelleted feeds, 50% pelleted, 50% pelleted-ground, ground and mash feeds on 21 to 42 d broiler chickens, and found that they selected large particles first when given the opportunity. Krabbe (2000), cited by Penz (2002) also confirmed the preferences identified by Klein (1996) when evaluating change in nutrient intake proportion as a function of GMD of 1 to 7 d broiler chicken feeds. Penz (2002) stated that this author found that chickens ingested adequate amounts of protein, calcium, phosphorus and sodium when eating feeds with a GMD of 635μm.

Table 1.2 *Effect of maize particle size on broiler performance during the first 7d of life*

Variables	Texture (mm)		
	Fine	Medium	Coarse
GMD	0.75-0.67	1.13-1.23	2.01-2.10
Body weight (g)	127	131	126
Food intake (g)	106	106	111
Food efficiency	0.679	0.670	0.659

Adapted from Nir *et al.*, 1994b

Penz (2002) mentioned that Krabbe (2000) also studied the effect of pre-starter feed particle size on broiler chicken performance, but that this author could not confirm the findings of Nir *et al.* (1994b). In Krabbe's work, both small and large particles impaired performance. Moreover, he did not identify any effect of GMD on water consumption during the first seven days of life of the broilers.

There have been conflicting research findings on whether it is more efficient to use large or small grain particle size for improved performance with recent studies favouring the use of coarse particle size.

1.4 Effect of using pellets on performance

Pelleting is a process whereby feed is passed through dies after treatment with steam. It has long been shown to improve performance, with some studies in the 1940s showing improvements in both growth rate and food conversion efficiency (Heywang and Morgan, 1944). An improvement in performance of broilers fed pelleted feeds has been attributed to hyperphagia (Bolton, 1960). However, Jensen *et al.* (1962) claimed that pelleting does not influence the amount of food consumed, but it decreases the time spent on food intake, and, consequently, the energy spent for consumption, leaving more energy available for growth.

Calet (1965) suggested that the pelleting process induces chemical changes that make nutrients more available to the animal. It induces changes to particle size and resistance, and this affects seasonal inputs related to food intake behaviour (McNaughton, 1984). Pelleting increases nutrient digestibility as a result of mechanical processing and the action of temperature as well as the partial hydrolysis of proteins, thereby changing their natural structures and releasing several nutrients by breaking down the cell walls (Moran, 1987).

Chickens prefer to eat particles that are smaller than their mouth cavity, and in addition they have very viscous saliva, the purpose of which is to lubricate the feed. If the pellet is unbroken the amount of saliva is sufficient to do this, but in they are offered mash or low quality pellet feeds, they need more saliva than they are capable of producing (Penz, 2002).

Klein *et al.* (1995), cited by Penz (2002), studied the effect of the feed form (pellets or mash) on energy metabolism in broiler chickens. They found that pelleting promoted food intake, energy retention and the efficiency of retention of apparent metabolisable energy

(AME). They also found that an increase in energy retention caused by pelleting did not affect the daily protein retention, but significantly affected the crude fat retention.

Some studies have evaluated the influence of particle size on pellet quality and found that a uniform particle size promotes water absorption, which is essential for pre-digestion of nutrients and for the production of harder pellets, and that the best pellets are obtained with larger maize particles (Calet, 1965).

Klein (1996), cited by Penz (2002), showed that independent of the physical integrity of the pellets, broiler performance is better when pellets rather than mash is fed. However, among pelleted feeds, better results were obtained in broilers fed unbroken pellets, which means good quality pellets are essential for better broiler performance. According to Penz (2002) pelleting feeds results in the production of a better quality carcass and better economic returns than crumbled or mash diets. The growth promoting effect of pellets may be due to an increased palatability, to an increased density of the food, and to the destruction of some growth inhibitors (Bolton, 1960).

1.4.1 Use of mini-pellets

The pelleting machine is composed of a die made up of holes of specific diameter (e.g. 1.8 and 3.44mm) through which the feed is forced under pressure to form pellets. Feeds for young broilers are usually supplied in a mash or crumbled form. The latter is a more expensive exercise, as pellets have to be made and then crushed. Recent studies have been conducted with mini-pellets being fed to broiler chickens during the first week of life. According to Penz (2002) these studies have shown that mini-pellets promote better performance both in the laboratory and under practical conditions when they were compared with pre-starter mash (Table 1.3).

Table 1.3. *Comparison of pre-starter mash or mini-pelleted diets on the performance of broilers from day-old to 7 d of age (Penz, 2002)*

Treatment	Weight gain (g)	Body weight (g)	Feed intake (g)	Feed efficiency
Prestarter-mash (1-7d)	132[b]	177[b]	167	0.83
Pre-starter mini-pellets (1-7 d)	154[a]	199[a]	165	0.94
Probability	0.00002	0.00001	0.98	0.06
CV (%)	5.3	3.6	13.0	12.4

a, b means in the same column with different significant levels (P<0.005)

The effect of pelleting was initially thought to be due to increased food intake, but it has been shown to reduce energy expenditure, thereby reducing food intake in some cases, and in others giving improved food conversion efficiency (Kilburn and Edwards, 2001).

1.5 Use of betaine in broiler feeds

Practical feed formulation for commercial broiler chickens dictates that feeds be developed to optimise live performance and product yield in the most economic manner possible (Jin, 2002). Betaine, a natural occurring substance found in a wide range of plants and animal species, has received considerable attention regarding its inclusion as an ingredient in animal feeds. Betaine is a metabolite of choline that donates methyl groups to homocysteine to form methionine (Jin, 2002).

The significance of betaine in chicken nutrition was first shown in the early 1940s (McGinnis *et al.*, 1942; Almquist and Grau, 1943, 1944). In order to determine the role of betaine in chickens, these researchers fed semi-purified feeds supplied with various levels of betaine, methionine, or choline and evaluated growth and perosis in chickens. Betaine inclusion in semi-purified feeds improved the growth rate of chickens, but to a less extent than methionine and choline (McGinnis *et al.*, 1942). However, Almquist and Grau (1943) showed that, although betaine improved growth, the improvement was lesser than that obtained with choline. They also established that the inability of betaine to stimulate growth when added to a purified feed was due to higher methionine content. McGinnis *et al.* (1942) found an improved growth rate as well as the prevention of perosis when betaine was used.

Early biochemical studies led to the conclusion that betaine is formed from choline and that growth responses obtained from betaine are due to its ability to provide methyl groups. Subsequent biochemical studies established that betaine donates methyl groups to homocystine to form methionine (Figure 1.1), and that this can spare methionine, a methyl donor, by recycling homocystine.

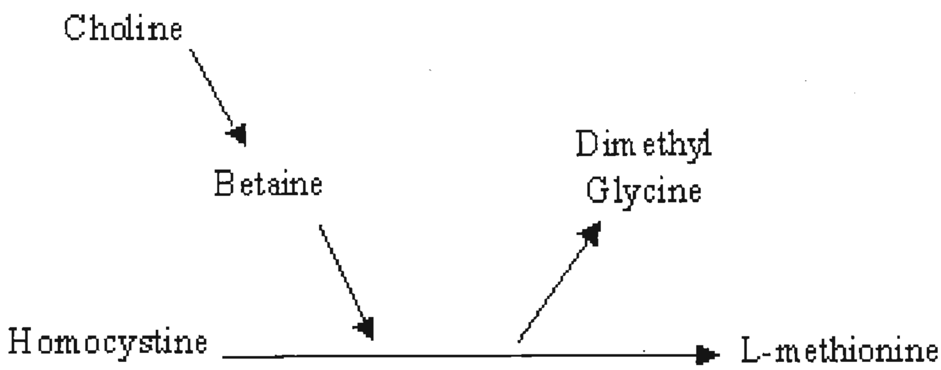

Figure 1.1 *The process of betaine synthesis and its conversion to methionine (Jin, 2002).*

Apart from being a methyl donor other roles of betaine are not well known, but Jin (2002) stated that betaine plays a crucial role in poultry production in terms of improving performance and economic benefits. This was in agreement with the suggestion by Penz (2002) for the use of betaine in broiler production. According to Jin (2002) betaine can play the following roles in broiler production:

- Provide methyl groups, which are fundamental for life. These methyl groups are involved in a number of metabolic reactions, for example, the creation of phospholipids (an important component of cell membranes), tissue repair and immune response functions.

- Provide more energy for animal growth, as it helps animals to maintain water balance in a more energy-efficient way, resulting in improved feed efficiency.
- It helps to maintain the balance in water and ions within the animal's body cells. This is important for the animal's health and the overall well-being of the animal.
- Helps reduce fat deposition in chickens, resulting in the production of lean carcass as per consumer requirements.
- Helps the chicken cope with heat stress caused by high temperatures.
- Increases breast yield and carcass yield.
- Gives opportunities to reduce feed cost, via the sparing effect on energy and via sparing effect of methionine and choline in the feed.

1.6 Utilization of fats by young broilers

Fat digestion occurs mainly in the small intestines, and this part of the digestive process is not fully developed during the first week of life (Noy and Sklan, 1995). According to these authors about 90% of the intestinal growth takes place during the first 5 d of age. There is also a rapid development of the digestive processes during the first week of age, to permit maximum absorption of fats by the second week of age (Carew *et al.*, 1972). During the first week of age certain changes (e.g. development of intestinal villi) are still necessary to make the digestive system fully functional (Noy and Sklan, 1995). Moreover, young broiler chickens lack the full physiological capacity for fat absorption, which is probably associated with insufficient bile acids to cope with fat digestion.

Young broiler chickens have a marginal supply of lipase enzymes and important co-factors necessary for digestion and absorption of fats and fatty acids (Leeson and Zubair, 2000). They recycle bile salts less efficiently, and this may be a factor that explains poor fat digestion.

Digestion of fats by chickens varies widely depending upon type of fat, level of saturation, age of the chicken and level of fat inclusion in the feed (Kantongole and March, 1980; Wiseman, 1984). Katongole and March (1980) found that young broiler chickens do not utilise and absorb fats effectively, especially animal fats, due to limiting lipase concentration and the lack of bile secretions. Edwards (1962) observed an improvement in the utilisation of dietary fats by young broiler chickens when the feed was supplemented with bile salts, and Katongole and March (1980) showed an improved utilization of tallow by young chickens offered feed supplemented with bile salts. While Leeson and Zubair (2000) showed that tallow is one of the least digested ingredients used in poultry feeds during the first three weeks with vegetable fat being the highest (Table 1.4).

Table 1.4 *Digestibility and metabolisable energy of some common feed grade fats as affected by the age of bird*

	Digestibility (%)		Metabolisable energy (kcal/kg)	
Age	0-21 d	>21 d	0-21 d	>21 d
Fat Type:				
Tallow	80	86	7400	8000
Poultry Fat	88	97	8200	9000
Fish oil	92	97	8600	9000
Vegetable oil	95	99	8800	9200
Coconut oil	70	84	6500	7800
Palm oil	77	86	7200	8000
Vegetable soap stock	84	87	7800	8100
Restaurant grease	87	96	8100	8900

Adapted from Leeson and Zubair (2000)

1.7 Sodium requirements of young broilers

Sodium and chloride are minerals with important physiological functions. An optimum balance between sodium and chloride promotes better chicken performance and may reduce leg problems (Britton, 1991).

The requirement for sodium by growing broilers decreases as they approach maturity, with highest requirement during the first 21 d (Underwood and Suttle, 1999).

The NRC (1984) recommended a minimum requirement of 0.15% sodium in the feeds of young broiler chickens. However, Britton (1991) reported that to obtain the best body weight gain, sodium level should be 0.20% of the feed. The NRC (1994) approved the latter finding by increasing their recommended inclusion to be the same as that of Britton (1991).

With the aim of verifying broiler nutritional requirements from 0 to 21 d, Murakami *et al.* (1997) conducted an experiment and found that the best body weight gain coincided with 0.25% dietary sodium.

1.7.1 Utilisation of high sodium feeds

The use of a pre-starter feed allows the use of high sodium contents in young broiler chickens, as they are fed that diet for only a short time. Oviedo-Rondon *et al.* (2001) found that dietary sodium levels have a quadratic effect on body weight gain, food intake and food conversion ratio. They found maximum body weight gain and food intake with 0.25% dietary sodium. This concurs with the findings of Murakami *et al.* (1997), who reported that any sodium content above 0.25% has no beneficial effect on performance. High dietary sodium contents have been found to increase the moisture content of the excreta as it results in an increase in water consumption of the chickens, which could cause illness, and leg problems where the humidity is very high (Damron *et al.*, 1986). However, Oviedo-Rondon *et al.* (2001) and Penz (2002) stated that although high sodium feeds do increase water intake, they do not increase water content of the excreta (Table 1.5).

Table 1.5 *Effect of sodium supplementation on water consumption, feed intake, weight gain, feed conversion and excreta moisture during the first week of life (Penz, 2002)*

Total Na (%)	Water intake (ml)	Feed intake (g)	Weight gain (g)	Feed conversion (g/g)	Excreta moisture (%)
0.10	213^{a}	124^{a}	67^{a}	1.85^{a}	68.3
0.22	282^{b}	139^{b}	104^{b}	1.34^{b}	69.7
0.34	303^{bc}	148^{b}	$116b^{c}$	1.28^{b}	70.9
0.46	322c	147b	119c	1.24b	71.0

Sodium bicarbonate or sodium chloride was found not to differ as sodium sources, while moisture content was found not to be related to sodium source but to sodium level; and that neither level nor source of sodium has any apparent effect on tibial dyschondroplasia (Murakami *et al.*, 1997).

1.8 Effect of utilizing food additives on performance

1.8.1Growth promoters

The term growth promoter is used to describe medicine that destroys or inhibit bacteria from competing with the animal for nutrients. Growth promoters are known to improve growth and food utilisation of broilers (Foster and Stevenson, 1983). They do this by suppressing growth of microorganisms that compete with the chicken for nutrients (Bunyan *et al.*, 1977), thus making more nutrients available for growth. However, where chickens are infected with disease, growth promoters are used to build the immune system of the chicken by diverting the nutrients absorbed from the food away from sites of growth, resulting in a reduction in performance (P. Spring, 2003- personal communication).

Dafwang *et al.* (1987) found that stocking density affected the efficiency of growth promoters. These authors observed low response in growth and food utilisation and poor immune response at high stocking densities. Although the efficiency of growth promoters appears to be affected by environmental and management factors, their importance in chicken growth and profitability of the enterprise cannot be disputed even though both negative and positive responses had been observed (Rosen, 1995). Researchers have recorded a significant improvement in growth and food utilisation over the years due to the addition of food additives. The highest improvement of 6% in growth was that observed by Griffin (1980), with the utilisation of zinc bacitracin.

1.8.2 Vitamins

Vitamin is a collective term for a range of micronutrients that are indispensable in all animals for maintenance of production, health and ultimately, life. Success in meeting the requirements of chickens requires that feed be formulated with known and predictable levels of vitamins. Vitamins occurring naturally in the feedstuffs are ignored when formulating the feeds and the total requirements of the chickens are met by addition of vitamin premix. Nevertheless, it would be a mistake to believe that the quantities supplied by premixes are sufficient for chickens because as new, more productive genotypes are introduced, vitamin levels are likely to increase. Peebles and Brake (1985) found a an improvement when additional levels were added to the feed, thus indicating that even those vitamins that chickens are known to produce enoughmay have to be included in the diets for new genotypes. Kennedy *et al.* (1992) found an improvement in productivity (8.4%) with the addition of ascorbic acid. Sklan *et al.* (1994) reported an improvement in immune response of broilers with high levels of vitamin A.

1.9 Environmental requirements

Broiler producers wish to produce good quality chickens, which have good growth rates and food conversion efficiencies, but broiler chickens are often subjected to hostile environmental conditions in the house. Their ability to attain their potential growth rate is dependent on the environmental conditions in which they are kept (Emmans and Oldham, 1988). Therefore, it is important to examine the effect of the environment on performance. The environmental factor under consideration here is the temperature.

1.9.1 Temperature and chicken physiology

Physiology of broilers during early growth is different from that of older broilers (Noy and Sklan, 1995). Early in its life a chicken is poorly equipped with mechanism to regulate its metabolic processes to raise or to lower its body temperature (Charles, 1986). Thus, chilling or overheating during this crucial period can be disastrous, as it can lead to death of chickens. Although death in the first week is often believed to be the result of temperature extremes (May and Lott, 2000), chilling and overheating can damage young chickens without causing death (Deaton *et al.*, 1996). Research work showed that high brooding temperatures of about 35°C or higher cause highly significant cardiac output and blood pressure, and chicks may show slower growth rate (Deaton *et al.*, 1996).

1.9.2 Effect of environmental temperature on nutrient utilisation

Nutrient requirements have been commonly established in an environment protected from climatic extremes. For this reason such requirements are more relevant during optimum environmental conditions and are less appropriate when animals are exposed to stressful environments. Energy demand of an animal is increased by cold environmental conditions and the magnitude of these demands is moderated by total body insulation (Deaton *et al.*, 1996). Under most environmental conditions there is a continual net loss of heat from the body surface by conduction, convection and radiation (Emmans, 1981), with negative impact on nutrient utilisation by an animal. Thus, the animal will utilise some of the nutrients for maintaining correct level of body heat. Penz (2002) mentioned that seasonal effect must be taken into consideration, as birds require more amino acids during hot weather.

1.9.3 Effect of temperature on performance of broilers during brooding

The problem facing broiler producers is to determine the temperature that will not place any constraint on growth and food intake of the chicken. Temperature of the environment can be seen as providing both resources (in the form of heat) and constraints on the growth of the broiler chicken.

Chickens during the early growing period are unable to maintain their body temperature as older chickens do (Charles, 1986). Therefore, they need artificial heat during this time at a far higher level than older chickens, that is, they depend on the warmth provided by the producer. Failure of the producer to provide them with optimum temperatures can reduce profitability of the enterprise because of the reduced growth and development of poor food conversion, increased diseases, condensation and mortality (Deaton *et al.*, 1996). The optimum temperature at this stage of growth should be that which ensures that the chickens are comfortable, showing no signs of overheating or chilling. The exposure of young chickens to high temperatures is detrimental to their growth and food to gain ratio (Charles, 1986).

Charles (1986) reviewed the research findings on temperature requirements for potential growth and food efficiency and also acceptable brooding temperatures. He noted that a large variation exists between experiments, with complications arising from dry bulb temperature, air speed and radiation from the brooder. He recommended an ambient temperature of 31°C during the first few days of life. However, he strongly suggested adjusting ambient temperature to the needs of the chicks by evaluating their behavioural response.

Deaton *et al.* (1996) brooded chickens at different temperatures and found that body weight increased with an increase in brooding temperatures, while feed conversion showed the opposite effect (Table 1.6). This may be due to the fact that at low temperatures broilers catabolize amino acids to generate metabolic heat.

Table 1.6 *Measures of performance of broilers kept at different environmental temperatures*

Temperature (^{0}C)			Body weight (g)	Feed conversion (kg feed/kg gain)
Week 1	Week 2	Week 3		
35	33	31.3	803^a	1.35^a
33	31.3	29.5	796^a	1.37^{bc}
31.3	29.5	27.6	794^a	1.39^b
29.5	27.6	25.8	756^b	1.42^c

May and Lott (2000) conducted an experiment in an attempt to measure the influence of the temperature on growth and mortality of broiler chickens from 0-21 d of age. They found no influence of the environmental temperature on growth (Figure 1.2) and food conversion efficiency during the first week of life, but high influence of temperature on mortality at this age.

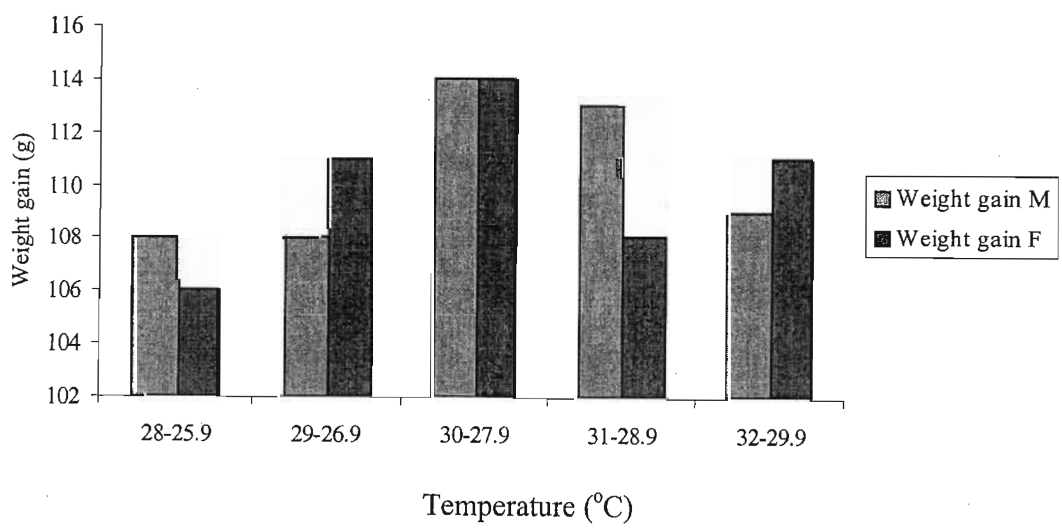

Figure 1.2 *Effect of temperature regime on weight gain of broilers from 0 to 21 d of age (May and Lott, 2000)*

1.10 Discussion

The importance of maximum chicken performance during the first week of life in broiler production is unquestionable. The problem of poor chicken performance originates from the under-utilisation of the nutrients supplied in the broiler feeds, either as a result of incorrect food formulation, or chickens not ingesting adequate amounts of food. Recently, a considerable amount of research has been focused on maximising broiler performance during the first week of life as a result of its effect on broiler performance to marketing age. Researchers showed that extra care must be taken in the first weeks, especially the first week of life of the chickens, to keep broilers on track in terms of growth, efficiency, and the overall health. It has been stipulated by many researchers that the key to maximum growth and food consumption is to keep chickens at ideal temperatures, with access to food that is well balanced. The availability of nutrients (including their digestibility), as a measure of how much of each ingredient has to be included in the pre-starter feed, need to be reviewed. The limitations and inadequacies of different nutrient compositions were discussed in this review. With maximum consumption as a key to optimum chicken growth, it was noted that chickens do not ingest adequate amounts of food. The most important constraint has been shown to be the intake of amino acids. The use of a pre-starter feed offered during the first week of life has become a popular option to supply the amino acids at a higher concentration than would be economical in a starter feed offered for two or three weeks, and the composition of such a feed has undergone continual improvement.

It is evident that the ability of chickens to attain their genetic potential depends on the quality of food offered and the environment under which they are reared. One of the most important nutritional factors that has to be met for chickens to achieve their genetic potential is their ability to consume adequate amount of amino acids. Recent work by researcher showed significantly high response of broilers fed high protein diets, thus, showing that the latest genotypes need to consume more amino acids each day than was the case in the past for them to reach their genetic potential. This leads to a need to increase the concentration of dietary amino acids and essential nutrients. However, even where one employs the latter, in some cases persistent poor performance occurs leading to an increasing need to develop new ways of maximising chicken growth. It appears that one way of encouraging chickens to consume adequate amounts of food is using high dietary sodium levels, of about 2.5g/kg, as this encourages the chickens to increase water intake, and thereby increase food consumption.

Pelleted feed looks to be a more successful way of improving the efficiency of utilisation of food by broiler chickens at all growth stages than using mash feed. Pellets been shown to reduce maintenance requirements of young broilers, which is very useful mostly where chickens cannot consume adequate amount of food. The desire shown by chickens to consume coarse feed particles makes the use of pellets more significant. Penz (2002) has shown that it will pay producers to spend money in pelleting the pre-starter feed. Penz (2002) has suggested that the mini-pellet die should be between 1.5 and 1.8mm.

A chicken at hatch has a potential growth path to maturity, which it will take, as long as conditions are ideal for it to do so. If these conditions are not adequate in the first week of life, the chick will not be able to compensate later for any nutritional insults received early in life. It is imperative, therefore, that the nutritional conditions conducive to ensuring that the chick will grow to its potential, are known. Some of these nutritional manipulations have been applied in this study in order to determine the factor(s) limiting early chick performance in the Brooder research facilities at the University of Natal.

Chapter 2

Nutritional factors that influence growth rate of broilers in the early growing period

2.1 Introduction

Genetic selection has played an important role in improving growth rates of broiler chickens over the years, resulting in a continued decrease in marketing age. This trend continues and emphasizes the importance of growth during the pre-starter period (that is, first week post-hatch). For the broiler chickens to be able to achieve their genetic potential, feeding has to start immediately after hatching, but this is often not the case, as chicks often arrive at the farm 36 to 48 h after hatching. But even where feeding begins soon after hatching, other factors appear to constrain growth and food intake in this period. These include the inability of the young chickens to ingest adequate amounts of feed as compared to older chickens, which leads to low intake of essential nutrients and food additives, which are critical for immune development and growth.

Nutrition of broilers during the first week of life is of utmost importance for production as any advantage gained by the broiler chickens during this period is maintained through marketing age (Noy and Sklan, 1995). Many nutritional studies have been conducted with broiler chickens. In general, these have commenced at 7 d of age, or the overall performance has been given for the first 2 or 3 weeks of life. The nutritional requirements of broiler chickens during the first week of life have largely been neglected by researchers, until recently. Hence, very little is known about the actual nutrient requirements of broiler chickens during the first 7 d of life.

High body weights of up to 197 g have been measured in some experiments at 7 d of age (Penz, 2002), but this has not been the case at Ukulinga research farm where the highest body weights achieved by 7 d usually fall below 160g (R. M. Gous, 2003-personal communication). It is essential for the future of poultry production that the constraints to achieving higher 7 d weights are identified and eliminated.

Penz (2002) suggested a number of interventions that may result in improved 7 d weights. These include the utilisation of high dietary amino acid contents, using temperatures lower than the comfort temperature, increased dietary sodium levels, pelleted as opposed to mash feeds, the use of relatively coarse grain particle size, the use of betaine and higher levels of food additives such as growth promoters.

Growth promoters have undoubtedly improved animal performance and the health status of broiler chickens. Visek (1978) reported that growth promoters limit the growth and colonisation of numerous non-pathogenic species of bacteria in the gut, including lactobacilli. By reducing bacterial growth, growth promoters have been shown to reduce the production of antagonistic microbial metabolites, such as ammonia (Rosen, 1995), which adversely affects the physiology of the host animal.

Subtherapeutic levels of growth promoters in the feed have been shown to reduce weight and length of the intestines, enhance nutrient absorption and reduce metabolic demands of the gastrointestinal tract (Visek, 1978). A reduction in the concentration of intestinal bacterial may also ease the competition for vital nutrients between the chicken and the microbes (Bedford, 2000).

Foster and Stevenson (1983) investigated the interaction of food additives and protein content on broiler performance at 0 - 22, 0 - 42 and 0 - 52 d of age. These authors used four levels of dietary protein (164, 181, 204, 216g CP/kg) and a growth promoter (zinc bacitracin at 500mg/kg). They found a significant improvement in body weight gain and food utilisation, and little improvement in food intake. Rosen (1995) detailed the mechanism of growth promotion and reported that the response to growth promoters has decreased over the years, but they still play a vital role in improving chicken performance, with an overall improvement of 11%. Both positive and negative responses have been observed (Rosen, 1995).

This experiment was designed to identify some of the possible constraints that may limit the performance of broiler chickens in the early growing period. These include the dietary crude protein content, the vitamin and trace mineral contents, and the need for a growth promoter and coccidiostat.

2.2 Materials and methods

2.2.1 Birds and housing

Four hundred and eighty day-old sexed Ross broiler chickens were purchased from National Chick Farms. They were housed in a brooder room at Ukulinga research farm. Forty-eight cages were used, with ten broiler chickens being randomly selected and placed in each cage, the sexes separate. Chickens were kept in these cages for the duration of the experiment (1 to 21 d). Single tier broiler cages measuring 80 x 50 cm were used in this trial. Two nipple drinkers were available in each cage. Both feed and water were supplied *ad libitum*. Birds were supplied with heat through a gas heater blower. The desired low temperature of 29.5^{0}C was set at the start of the trial and was reduced during the growing period, so that the temperature was about 23°C at 21 d of age. Both maximum and minimum temperatures were recorded every day. Chickens were weighed in groups of ten chickens per cage on arrival and also at the end of each week. The trial was terminated when chickens were 21 d of age.

2.2.2 Feeds and feeding procedure

Two basal feeds, one high (P_1) and the other low (P_3) in protein were formulated (Table 2.1) using Winfeed to obtain a well-balanced amino acid mixture (EFG broiler growth model, Emmans *et al.,* 2002). These diets were isocaloric (that is, 13MJ ME/kg) and contained the same contents of major minerals (Ca, P, Cl, K). The basal feeds were blended in appropriate proportions (50:50) to produce a feed with an intermediate protein level (P_2). The resultant three feeds were fed alone, or with the addition of vitamins and trace minerals at 2.5g/kg, or with the addition of both coccidiostat (2g/kg Avatec containing 0.3g lasalocid) and a growth promoter (zinc bacitracin at 330mg/kg), and a combination of all food additives (Table 2.2). The two basal feeds were sampled after mixing, and these samples were analysed for apparent metabolisable energy (AME) and digestible amino acid content. The nutrient and chemical composition of the two basal feeds used in this trail are shown in Table 2.1. . A feeding trough with a feed saver grid to avoid feed wastage by chickens, was allocated to each cage, as well as a 5 kg feed bin, which was filled with the test feed and then weighed at the beginning of the experiment. Feed was transferred from these bins to the feeding trough when necessary. At the end of each week the feed remaining in each trough was returned to the bin, which was then weighed to determine the amount of food consumed by the chickens during the week

Table 2.1 *Composition (g/kg) of the two basal feeds used in the trial. Amino acids are reported as totals*

Ingredient	P_1		P_3	
Maize	521		823	
Wheat bran	-		319.9	
Soybean full fat	250		124.1	
Soybean 46	343.7		-	
L-lysine HCl	0.1		1.4	
DL methionine	2.2		0.2	
Vit + mineral premix	2.5		2.5	
Limestone	15.7		20.4	
Salt	2.6		2.4	
Monocalcium phosphate	16.4		10.4	
Sodium bicarbonate	3.4		3.7	
Oil-sunflower	63.3		95.0	
Nutrient	Calculated	Analysed	Calculated	Analysed
Protein	299.0	298.9	141.0	140.8
AMEn (MJ/kg)	13.0	14.4	13.0	14.2
TMEn (MJ/kg)		14.9		14.6
Dry matter (%)	89.0	89.7	88.9	89.4
Total amino acids				
Threonine	9.4	10.9	4.9	4.7
Valine	10.2	17.7	4.3	8.5
Methionine	4.9	4.1	2.1	2.9
Isoleucine	8.9	15.0	3.7	5.9
Tyrosine	8.2	6.0	3.4	2.6
Phenylalanine	8.2	11.7	3.4	4.8
Leucine	15.6	24.5	6.5	10.6
Histidine	5.2	7.0	2.2	3.5
Lysine	14.9	17.6	6.2	7.8
Arginine	14.9	18.4	6.2	8.2

[4]Chemical composition were calculated using Winfeed on as is basis by Feed Evaluation Unit, University of Natal, 2002.

2.2.3 Experimental design

The experiment was a completely random design with no blocking. Each treatment was replicated twice, with each group of ten birds per cage representing a replicate. The experiment consisted of three protein levels, two vitamin levels, two growth promoter plus coccidiostat levels and two sexes, giving a 3x2x2x2 factorial design.

Table 2. 2 *Description of the dietary treatments used in the trial*

Treatment	Summit	Dilution	Vitamins	G+c[1]
1	100	0	0	0
2	50	50	0	0
3	0	100	0	0
4	100	0	+	0
5	50	50	+	0
6	0	100	+	0
7	100	0	0	+
8	50	50	0	+
9	0	100	0	+
10	100	0	+	+
11	50	50	+	+
12	0	100	+	+

[1] *G = growth promoter, c = coccidiostat*

2.2.4 Statistical analysis

Body weight gain, food intake (FI) and food conversion efficiency (FCE) were the tested response variables. The raw data of all the tested variables for the surviving chickens were inserted into Genstat 6.1(2002), and analysed. Treatment means and standard error of the means were obtained from analysis of each variate. The differences between mean values were identified using least significant differences (LSD). Linear and quadratic regressions were fitted to the data, using either protein intake (for growth rate) or protein content (for food intake and FCE) as the explanatory variable. The effect of food additives on these responses was measured using the 'group' option in Genstat 6.1.

2.3 Results

2.3.1 Body weight gain

Body weight gain increased significantly (P<0.05) as the protein content in the unsupplemented feeds increased from 141g CP/kg to 220g CP/kg feed. In excess of 220g CP/kg growth showed a declining trend (Figure 2.1; Table 2.3). At the lowest protein level, the addition of vitamins alone improved performance. In fact, growth rate was lower than on the negative control at the 220g CP/kg protein level when vitamins alone were added to the feed, but growth was significantly (P<0.05) improved when all additives were included at this protein level. Performance was not significantly improved in any treatments at high dietary protein level. Female broiler chickens gained more weight than males in all treatments (Table 2.3).

2.6.2 Food intake

The highest food intake was recorded on feeds with the highest protein content (Table 2.3 and Figure 2.2). Intake was reduced by the addition of G+c and V, the reduction being the same at each protein level. However, at the lowest protein content used these two feed additives increased food intake to that of the control treatment, there being no significant difference in intake between treatments on this feed. Although, highest food consumption was noted when V and a G+c were added on low protein feed, their addition on medium feeds significantly (P< 0.05) depressed food intake. The addition of food additives on medium and high protein levels failed to show any improvement in food intake.

Table 2.3. *Main effects and interactions of broilers fed feeds with and without food additives from 0 - 7 d of age, with SEM and LSD (5%)*

	Body weight gain (g/bird d)			Food intake (g/bird d)			FCE (g gain/kg feed consumed)		
	M	F	M/F	M	F	M/F	M	F	M/F
P_1	9.1	9.0	9.1	19.0	16.5	17.8	479	545	512
P_2	7.5	9.5	8.5	17.5	15.5	16.5	429	613	521
P_3	6.0	6.0	6.0	16.0	15.0	15.5	375	400	388
Mean	**7.7**	**8.2**	**7.9**	**17.5**	**15.7**	**16.6**	**428**	**519**	**474**
P_1+V	9.0	8.5	8.8	17.0	16.0	16.5	529	531	530
P_2+V	6.0	8.5	7.3	16.5	13.0	14.8	364	654	509
P_3+V	6.9	7.6	7.3	15.5	16.5	16.0	445	461	453
Mean	**7.3**	**8.2**	**7.8**	**16.3**	**15.2**	**15.8**	**446**	**549**	**497**
P_1+G+c	9.0	9.6	9.3	17.5	17.0	17.3	514	565	539
P_2+G+c	7.5	8.0	7.8	15.5	15.5	15.5	484	516	500
P_3+G+c	6.0	6.0	6.0	16.0	16.0	16.0	375	375	375
Mean	**7.5**	**7.9**	**7.7**	**16.3**	**16.2**	**16.3**	**458**	**485**	**471**
P_1+V+G+c	8.5	9.5	9.0	18.0	16.0	17.0	472	528	500
P_2+V+G+c	8.8	9.0	8.9	17.5	14.0	15.8	503	514	509
P_3+V+G+c	5.5	6.5	6.0	17.5	14.0	15.8	314	464	389
Mean	**7.6**	**8.3**	**8.0**	**17.7**	**14.7**	**16.2**	**430**	**502**	**466**
SEM Protein (n = 4)			0.293		0.357			11.63	
Additives (n = 12)			0.339		0.412			16.45	
LSD Protein (n=4)			0.856		1.04			33.96	
Additives (n = 12)			0.988		1.20			48.02	

M/F = male and females combined, V = vitamin, G+c = growth promoter+ coccidiostat

2.6.3 Food conversion efficiency

FCE increased significantly ($P < 0.05$) when the protein content was increased from low to medium on both unsupplemented and supplemented feeds, but this levelled off from medium to high protein diet (Figure 2.3). The addition of V to the low protein feed improved FCE. Addition of V to the feed containing 220g CP/kg showed a negative effect though not significant, but when added to high protein feed led to a positive response. Addition of either V or G+c resulted in an improvement in FCE only when chicks were offered the high protein feed. Chickens obtained their highest FCE when they were fed the medium protein feed as there was no significant improvement at the highest protein level. FCE increased, as the chickens grew older, with high protein levels showing highest food conversion at 21 d of age. FCE of males was below that of females in all treatments during the first 7 d, but was higher with the addition of all food additives at 21d (Table 2.4), but these differences were not significant.

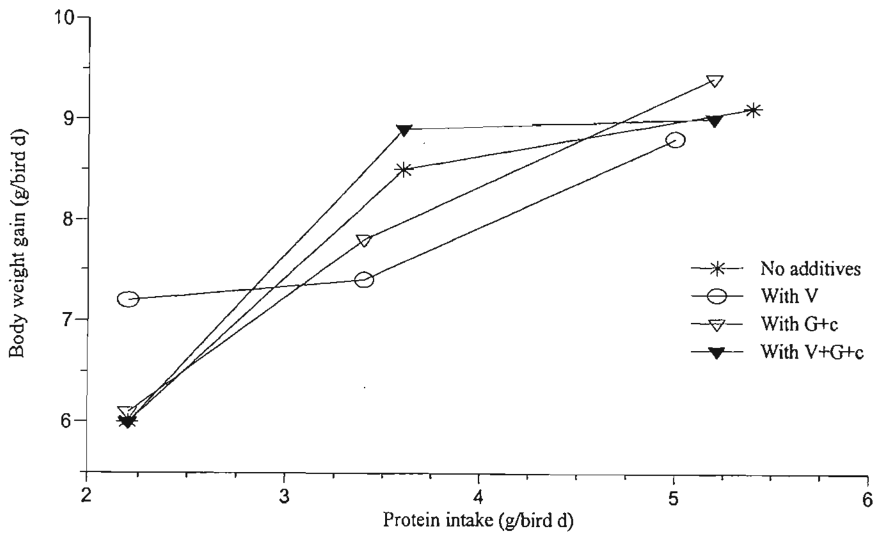

Figure 2.1 *Mean body weight gain of broilers fed diets with different nutrient composition from 0-7 d of age. With V = with added vitamins, with G+c = with added growth promoter and coccidiostat, with V+G+c= with vitamin and growth promoter plus coccidiostat*

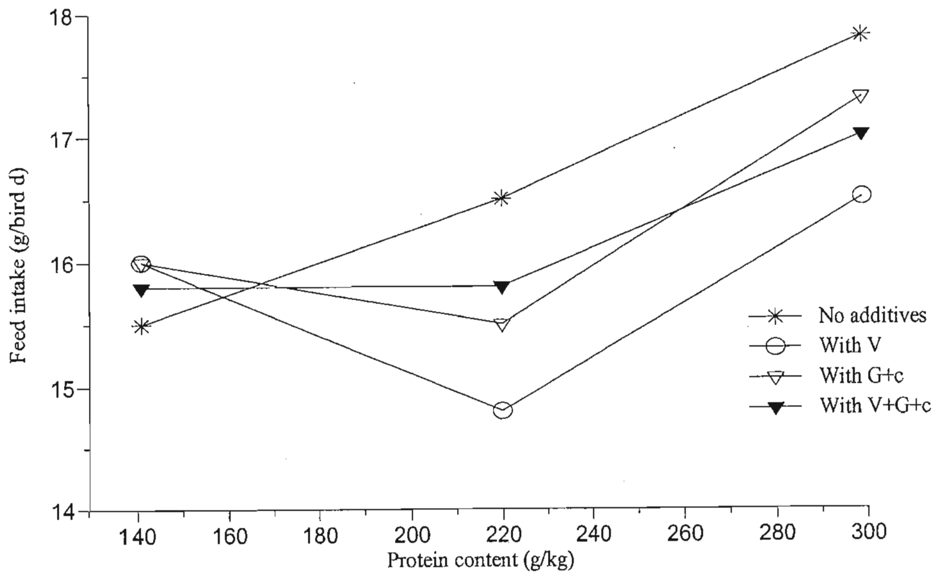

Figure 2.2 *Mean food intake of broilers fed diets with added vitamins, a growth promoter and the combination from 0 - 7 d of age*

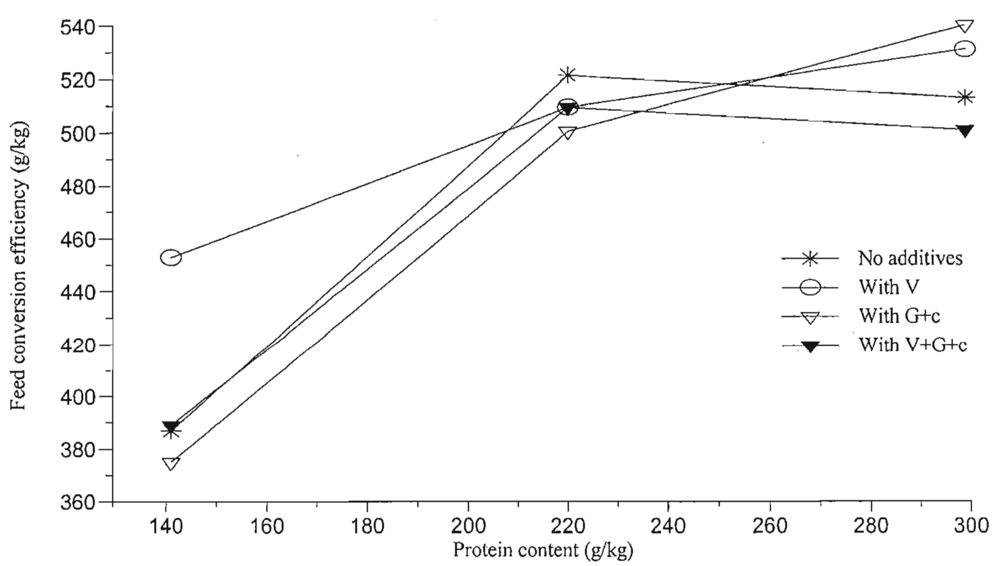

Figure 2.3 *Mean FCE of broilers fed diets with added vitamins, a growth promoter and the combination of all feed additives from 0 - 7 d of age*

Table 2.4. *Main effects and interactions of broilers fed feeds with and without food additives from 0 - 21 d of age, with SEM and LSD (5%)*

	Weight gain (g/bird d)			Feed intake (g/bird d)			FCE (g/kg)		
	M	F	M/F	M	F	M/F	M	F	M/F
P_1	28.0	25.5	26.8	39.5	38.5	39.0	714	651	683
P_2	24.5	25.5	25.0	36.5	37.5	37.0	664	666	665
P_3	15.0	13.5	14.3	38.5	33.0	35.8	378	410	394
Mean	**22.5**	**21.5**	**22.0**	**38.2**	**36.3**	**37.3**	**585**	**576**	**580**
P_1+V	24.0	26.0	25.0	38.5	37.3	37.9	681	679	680
P_2+V	21.5	24.5	23.0	37.5	36.8	37.1	611	658	634
P_3+V	15.0	14.5	14.8	34.0	35.5	34.8	400	426	413
Mean	**20.2**	**21.7**	**20.9**	**36.7**	**36.5**	**36.6**	**564**	**587**	**575**
P_1+G+c	26.0	26.5	26.3	38.0	38.8	38.4	661	682	671
P_2+G+c	22.0	24.0	23.0	36.0	37.5	36.8	564	680	622
P_3+G+c	15.5	13.0	14.3	32.5	34.5	33.5	434	395	415
Mean	**21.2**	**21.2**	**21.2**	**35.5**	**36.9**	**36.2**	**553**	**586**	**569**
P_1+V+G+c	27.0	26.0	26.5	39.5	38.8	39.1	719	660	689
P_2+V+G+c	25.5	23.0	24.3	37.0	37.0	37.0	678	627	652
P_3+V+G+c	14.5	14.5	14.5	34.0	34.0	34.0	423	422	422
Mean	**22.3**	**21.2**	**21.8**	**36.8**	**36.6**	**36.7**	**606**	**569**	**588**
SEM	Protein (n=4) 0.368			0.611			7.29		
	Additives (n=12) 0.425			0.706			8.42		
LSD	Protein (n = 4) 1.074			1.784			21.28		
	Additives (n = 12) 1.240			2.060			24.57		

M/F = male and female combined, V = vitamin, G+c = growth promoter+ coccidiostat

2.4 Discussion

The main objective of most broiler enterprises is to maximize profit from the operation and in order to achieve this, broiler chickens need to grow close to their potential from the moment that they are placed in the brooder house at day-old. This means that extra care needs to be taken early in the chickens' life to keep them on track in terms of growth rate, food conversion efficiency and overall health. The amount and quality of food, and the environmental factors, such as house temperature, air quality, and availability of water have a dramatic effect on the ability of the broiler chickens to attain their potential growth rate. Therefore, it is of utmost importance to identify constraints that have an adverse impact on the ability of the chickens to achieve their desired food intake and growth potential. The purpose of this trial was to identify some of the nutritional constraints to growth and food intake of broiler chickens in this early growing period.

The use of feed additives is the method that has been used by many researchers within this field of interest to improve broiler chicken performance. In the current trial a reduction in all measures of performance occurred to the addition of zinc bacitracin. The inability of the addition of zinc bacitracin to improve broiler performance may be attributed to the fact that growth promoters act on the adverse effect of bacterial infection on performance, and will show no effect on performance if chickens are not infected (Visek, 1978). This negative response observed in this trial is in accordance with some of the findings that have been reported in the review by Rosen (1995). Furthermore, Hays (1969) stated that when the house in which chickens are reared has been thoroughly cleaned and disinfected, growth of unsupplemented animals increased, while growth of animals given feed that was supplemented with growth promoters decreased.

The addition of vitamins and trace minerals failed to show any improvement in any of the measures of performance at medium and high dietary protein levels. However, their addition at low protein feed improved performance. Moreover, it is doubtful whether this increase of 1.3g/bird d is sustainable given that the other treatments in which addition of vitamins was included did not result in any positive response in growth rate. The improved performance at this protein level was not expected, because it was protein that was limiting growth at that level. It would be expected that at the highest protein level, where protein was not limiting, that the addition of vitamins might improve performance due to their assistance in the metabolic processes. However, no explanation for an improved performance with the addition of vitamins at low protein contents could be found in the literature. Further research on this could be interesting.

The significant positive response to an increase in dietary protein content from 141g/kg to 299g/kg shown by broiler chickens indicates a need by modern broilers for high protein levels in the feed. This improved performance occurs due to the fact that they have a greater growth potential, brought about by the intense selection for growth. The results of this experiment concurs with the findings of Parson and Baker (1982); Morris and Njuru (1990); Smith and Pesti (1998) and Smith *et al.* (1998), who observed significant improvements in body weight and FCE of broilers when they were offered feeds with the highest protein content.

2.5 Conclusions

The overall growth measured in this trial was below the normal weight obtained at Ukulinga, as it was 126g/d at 7 d of age. The feed additives used in this trial did not improve performance, which suggests that they were not limiting growth in the first period. The results showed that protein was the limiting factor on growth. The highest performance was achieved at highest protein content, but some constraints are still being placed on the broilers in this facility, which may not necessarily be related to the feed composition. Hence, in the next trial, a number of different interventions will be used in an attempt to identify the constraint to growth.

Chapter 3

The effect of dietary protein content, feed form and feed trough location on performance of broilers during the early growing period

3.1 Introduction

The objective of this trial is to discover what is constraining growth of broiler chickens in the existing broiler facilities at Ukulinga. Presently, feeds are offered in the mash form, and the feed trough is situated on the outside of the cage, thus, requiring the chickens to jump up and into the trough until they are large enough to stand in the cage and eat. This experiment was conducted to determine the effect of dietary protein content, the use of mini-pellets as opposed to mash feed, and the feeder location on performance of broilers.

Feeds for young broiler chickens are usually supplied in a mash or crumbled form. The latter is an expensive way of producing feed, as pellets have to be formed and then crushed, but feed conversion is invariably improved when pellets are fed. The beneficial effect of pelleting was thought by some to be due to the increased food intake that results, but it was shown long ago to reduce energy expenditure, thereby reducing food intake in some cases, and in others giving improved growth and food conversion efficiency (Heywang and Morgan, 1944). Recently, studies have been conducted on the use of mini-pellets fed to broiler chickens during the first week of life. These studies have shown that use of mini-pellets promotes better performance both in the laboratory and under practical conditions (Penz, 2002). It is suggested that mini-pellets of 1.5 to 1.8mm in diameter be used in pre-starter diets.

Chickens must initiate food intake and be able to digest and assimilate nutrients soon after hatching to be able to grow and be productive. However, young broiler chickens consume less food per day as compared to older chickens, which makes it difficult for them to ingest adequate amounts of food for their growth. The location of feed troughs inside the cages have been suggested as a possible means of increasing food consumption and performance of the young broiler chickens (R. M. Gous, 2002-personal communication), as this may improve food accessibility in the cages used at Ukulinga research farm.

3.2 Materials and methods

3.2.1 Animals and housing

Four hundred and eighty day old sexed Ross broiler chickens were obtained from National Chick Farm. These were housed in the brooder room at Ukulinga research farm. Forty-eight cages, each measuring 80 x 50cm were used, with ten randomly selected chickens being placed in each cage, the sexes separate. Chickens were kept in these cages for the duration of the experiment (1 to 21d). A feeding trough with a feed saver grid, to avoid feed wastage by chickens was allocated to each cage. Two nipple drinkers were available in each cage. Both feed and water were supplied *ad libitum*. The room was heated by means of a gas space heater. The desired temperature of 29.5^{0}C was set at the start of the experiment, and was reduced so that the temperature was about 21^{0}C at 21 d of age. Both maximum and minimum temperatures were recorded every day. Chickens were weighed in groups of ten birds per cage at the start of the trial and at the end of each week. The trial was terminated when chickens were 21 d old.

3.3 Feeds and feeding procedure

Two basal feeds, one high (P_1) and the other low (P_3) in protein and well-balanced amino acid mixture were formulated (Table 3.1) using Winfeed. These feeds were isocaloric (i.e. 13MJ ME/kg) and contained the same contents of major minerals (Ca, P, Cl, K). The dietary protein contents were 130 and 250g CP/kg for the low and high protein feeds, respectively. The two basal feeds were blended in appropriate proportions (50:50) to produce a feed with intermediate protein level (P_2 with 190g CP/kg). The three feeds were subdivided, and half of each feed was cold pelleted (P) using a 1.8mm diameter die while the other half was kept as mash (M). Two feed-trough locations were used to supply the feeds. The feeders were either placed inside the cages (internal) or outside (external). The two basal feeds were sampled after mixing, and these samples were analysed for apparent metabolisable energy (AME) and digestible amino acid content. The calculated and analysed chemical composition of the two basal feeds is shown in Table 3.1. A 5kg feed bin was allocated to each cage, and this was filled with the test diet and then weighed at the beginning of the experiment. Food was transferred from these bins to the feeding trough when necessary. At the end of each week the food remaining in each feed trough was returned to the bin, which was then weighed to determine the amount of food consumed by the chickens during the week.

Table 3.1 *Composition (g/kg) of the two basal feeds used in the trial. Amino acids are given as totals*

Ingredient	P_1		P_3	
Maize	521		823	
Soybean full fat	275.0		91.5	
Soybean 46	81.3		26.4	
Fish meal	100.0		18.3	
L-lysine HCl	0.4		2.1	
DL methionine	0.8		0.1	
Vit + mineral premix	1.5		1.5	
Limestone	10.1		17.3	
Salt	0.4		1.9	
Monocalcium phosphate	8.1		15.3	
Sodium bicarbonate	2.0		2.9	
Nutrient	Calculated	Analysed	Calculated	Analysed
Protein	250.0	250.1	130.0	130.3
AMEn (MJ/kg)	13.0	13.5	13.0	13.7
TMEn (MJ/kg)		14.1		14.1
Total amino acids				
Threonine	8.4	10.9	4.2	4.1
Valine	10.2	17.7	5.8	7.0
Methionine	4.9	4.1	2.3	2.6
Isoleucine	9.9	15.0	4.6	5.2
Tyrosine	7.6	6.0	4.1	3.0
Phenylalanine	9.6	11.7	5.1	5.9
Leucine	19.3	24.5	12.8	12.1
Histidine	5.9	7.0	3.3	5.2
Lysine	13.7	17.6	6.9	7.6
Arginine	14.8	18.4	6.9	7.9

[4]Chemical composition were calculated using Winfeed on as is basis by Feed Evaluation Unit, at University of Natal, 2003

3.4 Experimental design

The experiment was a completely random design with no blocking. Each treatment was replicated twice, with each group of ten chickens representing a replicate. The experiment was a factorial arrangement of fixed treatment effects consisting of three protein levels, two feed forms and two feed-trough locations and two sexes, giving a 3x2x2x2 factorial design.

Table 3.2. *Description of the treatments used in the trial.*

Treatment	Protein	Feed form	Trough location
1	P_1	M	In
2	P_1	M	Out
3	P_1	P	In
4	P_1	P	Out
5	P_2	M	In
6	P_2	M	Out
7	P_2	P	In
8	P_2	P	Out
9	P_3	M	In
10	P_3	M	Out
11	P_3	P	In
12	P_3	P	Out

3.5 Statistical analysis

Body weight, food intake and food conversion efficiency were the response variables. The raw data of all the tested variables for the surviving birds were inserted into Genstat 6.1 (2002), and analysed. Treatment means and standard errors of the means were obtained using an analysis of variance. The differences between the means were obtained using least significant differences (LSD). Linear and quadratic regressions were fitted to the data, using either protein intake, for growth rate, or protein content, for food intake and food conversion efficiency, as explanatory variables. The effect of feed form and feed location on these responses was measured using the 'group' option in Genstat.

3.6 Results

Body weight gains, food intakes and food conversion efficiencies (FCE, g body weight gain/kg food consumed) to 7 d and to 21 d are given in Tables 3.3 to 3.8 and Figures 3.1 to 3.3 for the first 7 d of the trial. Linear and quadratic coefficients for all measures of performance to 7 d of age are given in Table 3.9.

3.6.1 Body weight gain

There were statistically significant improvements ($P < 0.05$) in body weight gain with an increase in dietary protein content from 130 to 250g CP/kg. Males gained slightly more weight than females in all treatments, except on medium and low protein mash where similar gains occurred up to 7 d.

Pelleting significantly ($P < 0.05$) improved body weight gains by an average of 1.4g/bird d at all protein levels and the level of improvement increased with an increase in protein content of the feed. The improved growth due to pelleting over mash was maintained to 21 d of age. The average improvement when offering pellets was 2.7g/bird d and 3.7g/bird d at 7 and 21 d of age, respectively.

When the feed troughs were located inside the cages body weight gain in both feed periods was significantly ($P < 0.05$) improved. Highest weight gains by the broiler chickens was observed due to the location of pellets inside the cages, and the lowest gains occurred when mash was located outside the cages in all dietary protein levels.

Dietary protein content showed a significant ($P < 0.001$) quadratic response in body weight gain up to 7 d. The response differed depending on whether mash or pellets were fed, with better performance (1.4g/bird d) being due to pelleting. No significant differences in body weight gain occurred between feed-trough locations (Table 3.9).

3.6.2 Food intake

Over all treatments, food intake was lowest on the low protein feed and, except for broiler chickens fed mash in troughs outside the cage; it was highest on the medium protein feed (Table 3.5). Where food was offered inside the cage, highest food intake occurred when broiler chickens were fed medium protein mash. Similar food intake for the latter feed form occurred at low and high protein levels. No improvement in the intake of low and medium protein pellets occurred when these were located inside the cage. On average, the location of food inside the cages significantly ($P < 0.05$) increased food intake during both periods studied. Similar food intakes occurred when the two feed forms were used to 7 d of age. The chick consumed significantly ($P < 0.05$) more pellets than mash up to 21 d of age.

3.6.3 Food conversion efficiency

The lowest FCE recorded was where broilers were offered the low dietary protein feed. This increased significantly ($P < 0.001$) with an increase in dietary protein content by 7 d of age (Table 3.7). No significant differences in FCE were observed between medium and high protein feeds up to 21 d of age, but broiler chickens on both these dietary protein levels utilised food significantly ($P < 0.05$) more efficiently than those on low protein feed (Table 3.8). FCE was significantly improved by offering broiler chickens pellets over all treatments, with an enormous improvement when chicks were fed the low dietary protein feed in pelleted rather than in the mash form, the average improvement being 86 and 40g/kg at 7 and 21 d of age, respectively. The location of feed troughs had no significant effect on FCE at either feeding period. Females utilized their food significantly ($P < 0.05$) more efficiently than the males to 7 d.
Regression coefficients showed that dietary protein content had a linear effect on FCE, and that there was a significant ($P < 0.001$) linear difference between mash and pellets with an improvement 89.8g/kg due to pelleting (Table 3.9). There was also a linear improvement of 8.4g/kg due to the location of food outside the cage.

Table 3.3 *Main effects and interactions of protein content, trough location and feed form on body weight gain (g/bird d) from 0-7 d, with SEM and LSD (5%)*

	Mash						Pellets					
	In			Out			In			Out		
Protein	M	F	M/F	M	F	M/F	M	F	M/F	M	F	M/F
P_1	13.7	14.3	14	13.5	12.8	13.2	16	15.6	15.8	14.7	14.2	14.5
P_2	12.3	12.9	12.6	11.1	11.1	11.1	13.6	13.2	13.4	13.3	13.7	13.5
P_3	8.4	8.7	8.6	8.1	8.1	8.1	9.1	10.0	9.6	8.9	9.2	9.1
Mean	**11.5**	**12**	**11.8**	**10.9**	**10.7**	**10.8**	**12.9**	**12.9**	**12.9**	**12.3**	**12.4**	**12.4**

Main effects	Protein			Feed form		Location	
	P_1	P_2	P_3	M	P	In	Out
	14.4	12.6	8.8	11.2	12.7	12.3	11.5

	SEM	LSD
48 observations	0.37	1.07
24 observations	0.21	0.62
16 observations	0.26	0.76

Table 3.4 *Main effects and interactions of protein content, trough location and feed form on body weight gain (g/bird d) from 0-21 d, with SEM and LSD (5%)*

	Mash						Pellets					
	In			Out			In			Out		
Protein	M	F	M/F	M	F	M/F	M	F	M/F	M	F	M/F
P_1	33.7	33.5	33.6	27.7	33.2	30.5	40.8	37.6	39.2	35.3	34.1	34.7
P_2	33.5	31.5	32.5	32.3	29.8	31.1	35.1	33.2	34.2	31.8	31.3	31.6
P_3	25	19.4	22.2	17.6	18.3	18	27	29.3	28.2	20.4	23.8	22.1
Mean	**30.7**	**28.1**	**29.4**	**25.9**	**27.1**	**26.5**	**34.3**	**33.4**	**33.8**	**29.2**	**29.7**	**29.5**
Main effects	Protein				Feed form					Location		
	P_1	P_2	P_3		M	P				In	Out	
	34.5	32.3	22.6		28	31.6				31.6	28	

	SEM	LSD
48 observations	1.34	3.90
24 observations	0.77	2.2
16 observations	0.94	2.8

Table 3.5 *Main effects and interactions of protein content, trough location and feed form on food intake (g/bird d) from 0-7 d, with SEM and LSD (5%)*

	Mash						Pellets					
	In			Out			In			Out		
Protein	M	F	M/F	M	F	M/F	M	F	M/F	M	F	M/F
P_1	19.1	16.6	17.9	15	16.3	15.7	17.4	16	16.7	15.9	16.2	16.1
P_2	18.5	18.9	18.7	15.1	16	15.6	17.2	17.2	17.2	17.7	17.9	17.8
P_3	18.2	17.1	17.7	12.9	14.5	13.7	14.3	15.7	15	14.4	16.3	15.4
Mean	**18.6**	**17.5**	**18.1**	**14.3**	**15.6**	**15.0**	**16.3**	**16.3**	**16.3**	**16.0**	**16.8**	**16.4**
Main effects	Protein				Feed form					Location		
	P_1	P_2	P_3		M	P				In	Out	
	16.6	17.3	15.4		16.5	16.4				17.2	15.7	

	SEM	LSD
48 observations	0.43	1.26
24 observations	0.25	0.73
16 observations	0.30	0.89

Table 3.6 *Main effects and interactions of protein content, trough location and feed form on food intake (g/bird d) from 0-21 d, with SEM and LSD (5%)*

	Mash						Pellets					
	In			Out			In			Out		
Protein	M	F	M/F	M	F	M/F	M	F	M/F	M	F	M/F
P_1	46.9	44.2	45.6	40.9	40.7	40.8	51.1	48.8	50	42.5	41	41.8
P_2	43.9	43.5	43.7	44.2	41.8	43	46.7	46.4	46.6	43.5	42.5	43.0
P_3	39.1	36.3	37.7	29.2	33.2	31.2	36.7	39.3	38	32.5	39.5	36.0
Mean	**43.3**	**41.3**	**42.3**	**38.1**	**38.6**	**38.3**	**44.8**	**44.8**	**44.8**	**39.5**	**41**	**40.3**
Main effects	Protein				Feed form					Location		
	P_1	P_2	P_3			M	P			In	Out	
	44.5	44.1	35.7			40.3	42.5			43.6	39.3	
				SEM				LSD				
48 observations				1.18				3.46				
24 observations				0.68				2.00				
16 observations				0.84				2.44				

Table 3.7 *Main effects and interactions of protein content, trough location and feed form on food conversion efficiency (g gain/kg food) (FCE) from 0-7 d, with SEM and LSD (5%)*

	Mash						Pellets					
	In			Out			In			Out		
Protein	M	F	M/F	M	F	M/F	M	F	M/F	M	F	M/F
P1	717	861	789	900	785	843	920	975	948	925	877	901
P2	665	683	674	735	694	715	791	767	779	751	765	758
P3	462	509	486	628	559	594	636	637	637	618	564	591
Mean	**615**	**684**	**650**	**754**	**679**	**717**	**782**	**793**	**788**	**765**	**735**	**750**
Main effects	Protein				Feed form					Location		
	P1	P2	P3			M	P			In	Out	
	870	731	577			683	769			719	733	
				SEM				LSD				
48 observations				17.4				50.7				
24 observations				10.0				29.3				
16 observations				12.3				35.9				

Table 3.8 *Main effects and interactions of protein content, trough location and feed form on food conversion efficiency (g gain/kg food) (FCE) from 0-21 d, with SEM and LSD (5%)*

	Mash						Pellets					
	In			Out			In			Out		
Protein	M	F	M/F	M	F	M/F	M	F	M/F	M	F	M/F
P1	713	765	739	678	818	748	788	771	780	777	757	767
P2	761	722	742	731	712	722	804	667	736	747	692	720
P3	641	532	587	604	552	578	730	743	737	628	607	618
Mean	**705**	**673**	**689**	**671**	**694**	**683**	**774**	**727**	**751**	**717**	**685**	**701**

Main effects	Protein			Feed form		Location	
	P1	P2	P3	M	P	In	Out
	758	730	577	683	726	720	692

	SEM	LSD
48 observations	25.3	52.2
24 observations	14.6	42.6
16 observations	17.9	73.9

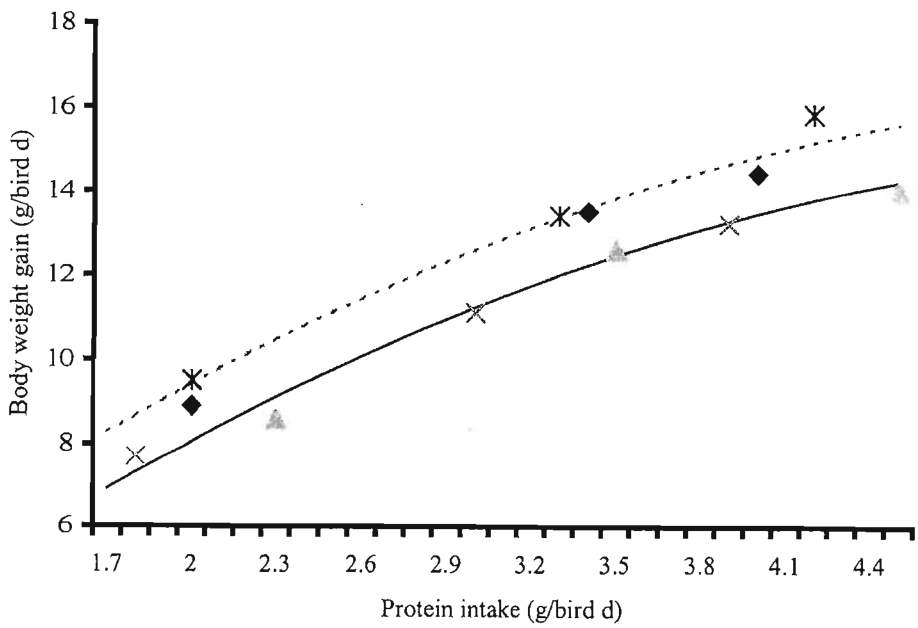

Figure 3.1 *Mean weight gain of broilers fed different feed forms (▲ mash in, X mash out, ✳ pellets in, ◆ pellets out) to 7 d of age irrespective of feed trough location*

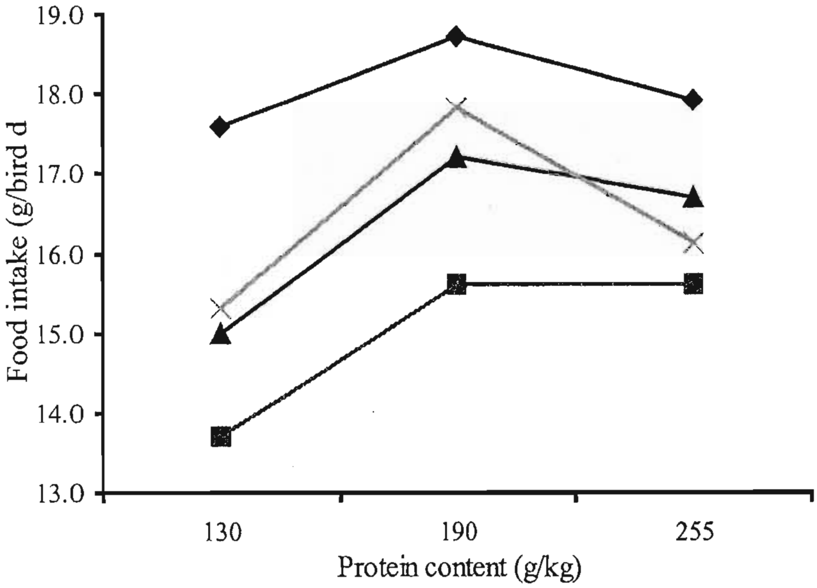

Figure 3.2 *Mean food intake of broilers fed different feed forms (◆ mash in, ■ mash out, ▲ pellets in, × pellets out) to 7 d of age, with feed trough location differentiated*

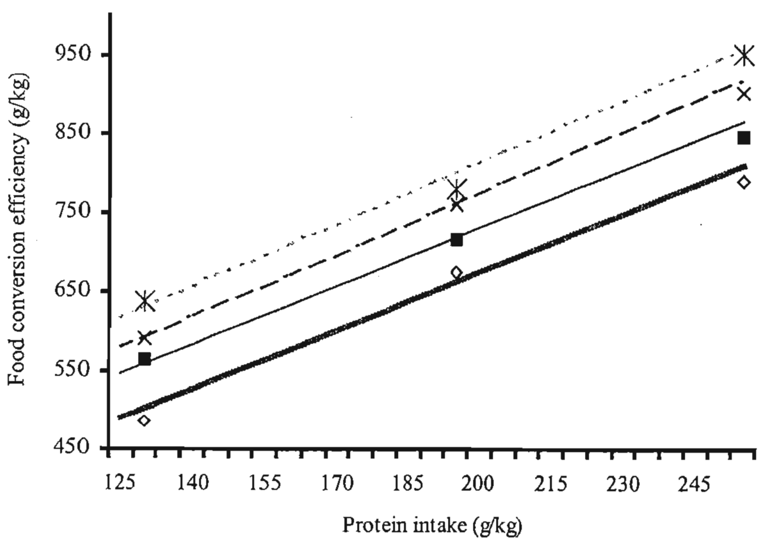

Figure 3.3 *Mean food conversion efficiency of broilers fed different feed forms (◇ mash in, ■ mash out, ✳ pellets in, × pellets out) to 7 d of age, with feed trough location differentiated*

Table 3.9 *Coefficients obtained from fitting curvilinear regressions of body weight gain and feed conversion efficiency (FCE) on dietary protein intake, with feed form and trough location as groups*

	Body weight gain		FCE	
Source	Coefficient	P value	Coefficient	P value
Constant [a]	-1.12	0.419	202.0	0.001
Protein intake	5.537	0.001	2.508	0.001
Protein intake^2	-0.474	0.004		
Feed form	1.366	0.001	89.8	0.001
Constant [b]	-1.5	0.427	242.5	0.001
Protein intake	6.37	0.001	2.508	0.001
Protein intake^2	-0.613	0.005		
Feed trough location	-0.154	0.615	8.4	0.673

Constant [a] = feed form. Constant [b] = feed trough location

3.7 Discussion

Young broiler chickens must initiate food intake and be able to digest and assimilate nutrients soon after hatching to be able to grow and be productive. This should be achieved by offering them a well-balanced feed that supplies nutrients at the desired concentrations. The significant increase in body weight gain of broiler chickens on both feed forms used in this trial, as the protein content of the feed increased, indicates that modern broilers need high dietary protein contents initially in order to grow at their potential. This may occur as selection for coarser particles which occurs when chickens are fed mash is prevented by pelleting. This result is in line with the findings of Swatson *et al.* (2000) who found an increased response in growth rate as the dietary protein content increased from 200 to 500g CP/kg.

Although weight gains with both feed forms increased with dietary protein level, the lowest gains over all protein levels were observed with broiler chickens consuming mash. This result is similar to that of Penz (2002) who observed significantly reduced weight gains when young broiler chickens were fed mash rather than pelleted feed. Furthermore, because body weight gain is highly dependent on nutrient intake, the improved performance obtained by feeding pellets has been attributed to hyperphagia (Bolton, 1960). The improved growth of broiler chickens fed pellets may have occurred due to reduced maintenance requirement, as had been stated in previous studies (Penz, 2002). Furthermore, it was noted in this trial that chicks fed pellets spent less time feeding, thus reducing the energy spent on consumption, which could have led to more energy being available for growth. Moreover, pelleting may increase intake of nutrients by bringing nutrients together, thus improving nutrient utilization in the feed. The results of feeding young broilers pellets is in contrast to the earlier findings by Calet (1965) who observed no improvement in growth due to pelleting feeds for young broiler chicks, but is in line with the findings of Hinds and Scott (1958) and Penz (2002) who claimed that the effect of pellets is more marked when the broiler chickens are very young.

Location of feed troughs inside the cages proved to be beneficial to growth of the broiler chickens, as shown by the significant improvement in weight gain with both feed forms. This improvement in weight gain may be attributed to improved food accessibility. This justifies the suggestion that the problem of inadequate food intake on growth of broiler chickens at Ukulinga may be improved by using feed troughs situated inside the cages (Gous, 2002-personal communication). This applies specifically to the brooder cages at Ukulinga, but it does highlight the importance of accessibility to food when feeding chicks.

The significant difference in food intake between mash and pellets, with high intake observed when broilers were fed mash may be attributed to the difference in maintenance requirement by the chickens to the two feed forms, with high maintenance requirement occurring when chickens were fed mash feed. This is contrary conclusion to that of Leroy (1961), that when the feed is supplied in mash form, the heat loss measured by respiratory exchange is considerably reduced thus reducing energy requirements.

The lowest food intake that occurred when the broiler chickens were fed low dietary protein pellets may partly be attributed to the hardness of these pellets. The low intake of the hard pellets may also be responsible for low FCE, as performance is directly related to food intake. This poor food intake of hard pellets is in accord with the findings of Allred *et al.* (1957) who found that very hard pellets are left uneaten by the chickens. These hard pellets may have occurred as a result of low concentrations of high fat ingredients in the feed. The quality of the food offered to the chickens has an influence on the appetite (Emmans and Fisher, 1986). This can be justified by the increased food intake as the quality was improved.

The significant improvement in food utilisation due to pelleting was not surprising, as it has constantly been noted with older birds (Calet, 1965) and with younger birds (Penz, 2002). Jensen *et al.* (1962) showed that while pelleting only slightly affects the number of meals, the duration of each meal is reduced three-fold in broiler chickens when the feed is pelleted. Although meal lengths and frequency were not objectively determined in this experiment, the subjective behavioural observations confirmed the above reports. In accordance with the conclusion of Savory (1974), who carried out behavioural studies, chickens fed pellets were less active, as they "sat" more and spent less time eating. The inability of allocation of mash feed inside the cages to improve food utilization beyond its location outside the cage may be attributed to food wastage, which was observed when inside troughs were used.

FCE was improved by pelleting the feed, independent of the amount consumed. This beneficial effect in food utilization due to pelleting occurred despite a decreased food intake due to hardness of low protein pellets. The hardness and length of low protein pellets observed may have had an adverse effect on the adaptation of the gastro-intestinal tract, and affected the bird's overall response to feeding pellets during the periods studied. The improved food utilization that occurred when pellets were used indicates that large particles are suitable for the young chicks and may have enhanced development of the intestinal tract compared to mash feed.

3.8 Conclusions

Dietary protein content was positively related to performance. Chicks showed a positive response in all measures of performance when the feed troughs were placed inside the cages, except for food intake when mash was located in this position. The positive response of the chicks to pelleting also proved that pelleting is beneficial for young chicks.

Chapter 4

The effect of dietary protein content, feed form and brewer's yeast (*Saccharomyces cerevisiae*) on early performance of broilers

4.1 Introduction

Feeds differing in nutritional properties and form are the subject of the research being conducted here to determine the feed with the best overall effect on the early growth. In the first experiment, the effect of dietary protein content, addition of feed additives, that is, a growth promoter + coccidiostat, and vitamins + trace minerals on performance of young broiler chickens was investigated. These feed additives did not improve performance. In the second experiment, three dietary protein contents were again used, but in addition the effect of two feed forms (mash *vs.* pellets) and feed trough location (either inside or outside the cage) were studied. All these interventions were investigated in a quest to improve performance of young broiler chickens. It emerged in both experiments that dietary protein content had a profound effect on early broiler performance. At the time that these trials were taking place it was suggested that perhaps broiler chickens could benefit from the addition of brewer's yeast to the feed, so in the following experiment, this additive was tested, as was dietary protein content and the use of pellets *vs.* mash, once again.

Yeast is known to be a good source of B vitamins and is high in both protein and mineral contents. The yeast *Saccharomyces cerevisiase* has been reported by Devegowda *et al.* (1994) to improve the immune system, growth rate and FCE of chickens, although most studies with this yeast have concentrated on the use of its extracts, for example, mannan-oligosaccharides (MOS) on broiler performance (Iji and Tivey, 1998; Ziggers, 2003).

This experiment was designed to investigate the effect of dietary protein content, and to determine whether the addition of brewer's yeast in feeds for young broilers can result in improved growth and FCE in young broilers. It was also designed to determine whether birds fed mini-pellets perform better than those fed mash.

4.2 Materials and methods

4.2.1 Birds and housing

Four hundred and eighty day old sexed Ross broiler chicks were purchased from National Chick Farms. These were housed in the brooder room at Ukulinga research farm. Forty-eight cages were used, with ten randomly selected chickens being placed in each cage, the sexes separate. Chickens were kept in these pens for the duration of the experiment (1 to 21 d). Single-tiered, wire-floored broiler cages measuring 80 x 50cm were used in this trial. Two nipple drinkers were available in each cage. Both feed and water were supplied *ad libitum*. The room was heated by means of a gas space heater. The desired low temperature of 29.5°C was maintained throughout the brooder room for the first week, and this was reduced by 1°C twice a week thereafter. Both maximum and minimum temperatures were recorded every day. All chickens in each cage were weighed as a group on at the start of the trial and at the end of each week. Mortality was recorded as it occurred. The trial was terminated when the chickens were 21 d old.

4.2.2 Diets and treatments

The composition of the two basal feeds used in this experiment was the same as in the previous experiment. The dietary protein contents were 130 (P_3) and 250g CP/kg (P_1) for the low and high protein feeds, respectively. These two feeds were blended (50:50) to produce a feed with an intermediate protein level (P_2) with 190g CP/kg. These three feeds were fed alone, or with the addition of brewer's yeast at 16.7g/kg diet. Half of each diet was cold pelleted using a 1.8mm diameter die while the other half was left as mash, resulting in twelve treatments (Table.4.2). The two basal feeds were sampled after mixing, and these were analysed for apparent metabolisable energy (AME) and digestible amino acid contents (Table 4.2). Feed troughs were placed inside the cages for the first 10 d, after which the troughs were placed outside the cages. Each feeding trough contained a feed saver grid, to avoid feed wastage by chicks. A 5kg feed bin was allocated to each cage, and this was filled with the test feed and then weighed at the beginning of the experiment. Food was transferred from these bins to the feeding trough when necessary. At the end of each week the food remaining in each trough was returned to the bin, which was then weighed to determine the amount of food consumed by the chickens during the week.

Table 4.1 *Description of dietary treatments used in this experiment*

Treatment	Protein	Brewer's yeast	Feed form
1	P_1	0	M
2	P_3	0	M
3	P_2	0	M
4	P_1	+	M
5	P_3	+	M
6	P_2	+	M
7	P_1	0	P
8	P_3	0	P
9	P_2	0	P
10	P_1	+	P
11	P_3	+	P
12	P_2	+	P

4.3 Experimental design

The study was conducted as a completely random design with no blocking. Each treatment was replicated twice, with each group of ten birds representing a replicate. The experiment consisted of factorial arrangement of fixed treatment effects consisting of three protein levels, two feed forms, two levels of brewer's yeast and two sexes, giving a 3x2x2x2 factorial design.

Table 4.2 *Analysed chemical composition (g/kg) of the two basal feeds. The amino acids are given as totals*

Nutrients	P_1		P_3	
	Calculated	Analysed	Calculated	Analysed
Protein	250.0	250.9	130.0	135.0
AMEn (MJ/kg)	13.0	14.3	13.0	13.1
TMEn (MJ/kg)		14.8		13.5
Dry matter (%)	88.5	90.0	87.4	89.2
Total amino acids				
Threonine	8.4	8.5	4.2	4.0
Valine	10.2	13.5	5.8	6.4
Methionine	4.9	4.6	2.3	1.7
Isoleucine	9.9	11.7	4.6	5.3
Tyrosine	7.6	5.7	4.1	2.6
Phenylalanine	9.6	12.6	5.1	5.7
Leucine	19.3	21.4	12.8	11.9
Histidine	5.9	6.6	3.3	3.4
Lysine	13.7	15.3	6.9	7.3
Arginine	14.8	14.9	6.9	7.0

[4]Chemical composition was calculated using Winfeed on as is basis by Feed Evaluation Unit, at University of Natal, 2003

4.4 Statistical analysis

Body weight, food intake and food conversion efficiency (FCE) were the variables tested. The raw data of all the tested variables for the surviving birds were inserted into Genstat, and analysed using Analysis of Variance to test the level of significant differences between the treatments. Interactions between the dietary treatments were also tested. Treatment means and residual mean square (RMS) were obtained using an Analysis of Variance. The differences between mean values were identified by the least significant difference (LSD).

4.5 Results

4.5.1 Dietary protein content

Dietary protein content had highly significant ($P < 0.001$) effect on body weight gain, food intake and FCE (Table 4.3, 4.4 and 4.5). Body weight gain and FCE increased with an increase in dietary protein content (Figure 4.1 and 4.3), and this response was maintained until 21 d of age. The gains differed significantly ($P < 0.001$) between sexes, with females gaining more weight when offered medium and high protein up to 7 d, but similar gains were observed when they were offered low protein feed in both feeding periods (Table 4.3). Highly significant differences ($P < 0.001$) occurred between medium and high protein levels with low protein level in body weight gain (Table 4.4 and Figure 4.1) at both feeding periods. Chickens consumed more food when they were offered medium protein feed in both feeding periods, with lowest food intake obtained for chickens fed low dietary protein feed in both feeding periods (Table 4.4). Although chickens consumed more when offered medium protein feed, their FCE increased with an increase in dietary protein content, and this was maintained up to 21 d of age (Table 4.5).

4.5.2 Brewer' yeast

No improvement in any measures of performance occurred due to the addition of the yeast during either feeding period. Its addition to the feed containing high dietary protein resulted in an improvement in food intake for both feed forms up to 7 d of age (Figure 4.2), while an improvement in body weigh gain occurred at high protein (Figure 4.1), although this was not significant. There was no effect of brewer's yeast its effect on performance of both sexes in all parameters tested. Dietary protein content and yeast showed no significant interaction, thus showing that its response was the same over all protein levels.

4.5.3 Pelleting

There were significant ($P < 0.001$) improvements in body weight gain and FCE, but a similar food intake due to pelleting up to 7 d of age (Table 4.3). In fact, pelleting slightly improved food intake at both low and high dietary protein levels up to 7 d of age, with the highest consumption obtained when yeast was added at higher protein level (Figure 4.2).

At 21 d of age significant ($P< 0.001$) improvements in all measures of performance due to pelleting were observed. Pelleting resulted in an improvement of 2.4 and 3.0g/bird d in body weight gain with and without yeast to 7 d, respectively. The response in body weight gain due to pelleting increased with age of the chickens, as it resulted in an improvement of 7.7 and 7.8g/bird d, without and with yeast up to 21 d. FCE was highly improved by 150 and 183g/kg, up to 7 d, and decreasing to 56g/kg and 66g/kg up to 21 d without and with the addition of yeast. No significant interactions occurred between pellets and yeast in all measures of performance. In fact, similar improvements in food intake occurred due to pelleting the feed with and without the addition of yeast at 7 d of age (Table 4.4).

Table 4.3 *Main effects and interactions of protein content, feed form and yeast on body weight gain (g/bird d) for the age periods studied, with residual mean squares (RMS)*

		Mash						Pellets					
Age	Protein	No yeast			Plus yeast			No yeast			Plus yeast		
		M	F	M/F	M	F	M/F	M	F	M/F	M	F	M/F
	P1	10.8	11.7	11.3	10.5	11.9	11.2	11.8	15.6	13.7	15.0	14.8	14.9
0-7 d	P2	11.0	12.2	11.6	9.9	11.8	10.9	12.7	13.5	13.1	13.1	13.3	13.2
	P3	7.4	7.6	7.5	7.6	7.6	7.6	10.5	10.9	10.7	10.4	10.6	10.5
	Mean	**9.7**	**10.5**	**10.1**	**9.3**	**10.4**	**9.9**	**11.7**	**13.3**	**12.5**	**12.8**	**12.9**	**12.9**
	RMS							**0.703**					
	Main effects	Protein					Feed form				Yeast		
		P_1	P_2	P_3			M	P			0	+	
		12.8	12.2	9.1			10.0	12.7			11.3	11.4	
	P1	28.6	28.7	28.7	28.4	31.2	29.8	33.1	36.3	34.7	34.0	35.7	34.9
0-21 d	P2	27.9	29.1	28.5	23.6	28.3	26.0	36.3	35.7	36.0	35.0	35.3	35.2
	P3	18.4	18.4	18.4	18.4	18.9	18.7	27.7	28.0	27.9	27.1	28.6	27.9
	Mean	**25.0**	**25.4**	**25.2**	**23.5**	**26.1**	**24.8**	**32.4**	**33.3**	**32.9**	**32.0**	**33.2**	**32.6**
	RMS							**2.575**					
	Main effects	Protein					Feed form				Yeast		
		P_1	P_2	P_3			M	P			0	+	
		23.2	31.4	32.0			25.0	32.7			29.0	28.7	

Table 4.4 *Main effects and interactions of protein content, feed form and yeast on food intake (g/bird d) for the age periods studied, with residual mean squares (RMS)*

Age	Protein	Mash						Pellets					
		No yeast			Plus yeast			No yeast			Plus yeast		
		M	F	M/F	M	F	M/F	M	F	M/F	M	F	M/F
	P1	17.4	16.1	16.8	18.7	16.4	17.6	15.5	18.7	17.1	17.8	18.1	18.0
0-7 d	P2	18.9	20.1	19.5	20.3	17.6	19.0	17.2	17.3	17.3	16.1	17.7	16.9
	P3	15.4	16.1	15.8	15.3	15.6	15.5	16.1	17.2	16.7	16.6	16.3	16.5
	Mean	**17.2**	**17.4**	**17.3**	**18.1**	**16.5**	**17.3**	**16.3**	**17.7**	**17.0**	**16.8**	**17.4**	**17.1**
	RMS						**1.386**						
	Main effects	Protein					Feed form				Yeast		
		P_1	P_2	P_3			M	P			0	+	
		17.3	18.2	16.1			17.3	17.1			17.2	17.2	
	P1	42.9	42.6	42.8	40.9	44.2	42.6	49.4	48.9	49.2	48.7	49.5	49.1
0-21 d	P2	43.7	44.5	44.1	41.5	44.7	43.1	52.6	52.1	52.4	45.8	50.3	48.1
	P3	38.7	35.7	37.2	36.0	36.0	36.0	45.2	48.7	47.0	46.7	49.9	48.3
	Mean	**41.8**	**40.9**	**41.4**	**39.5**	**41.6**	**40.6**	**49.1**	**49.9**	**49.5**	**47.1**	**49.9**	**48.5**
	RMS						**8.471**						
	Main effects	Protein					Feed form				Yeast		
		P_1	P_2	P_3			M	P			0	+	
		45.9	46.9	42.1			41.0	49.0			45.4	44.5	

Table 4.5 *Main effects and interactions of protein content, feed form and yeast on food conversion efficiency(g gain/kg feed) (FCE) for the age periods studied, with residual mean squares (RMS)*

Age	Protein	Mash						Pellets					
		No yeast			Plus yeast			No yeast			Plus yeast		
		M	F	M/F	M	F	M/F	M	F	M/F	M	F	M/F
	P1	622	730	676	637	642	640	762	839	801	846	817	832
0-7 d	P2	583	611	597	562	584	573	740	776	758	753	814	784
	P3	477	474	476	489	501	495	650	632	641	639	640	640
	Mean	**561**	**605**	**583**	**563**	**576**	**569**	**717**	**749**	**733**	**746**	**757**	**752**
	RMS						**1.386**						
	Main effects	Protein					Feed form				Yeast		
		P_1	P_2	P_3			M	P			0	+	
		737	678	563			576	742			658	660	
	P1	681	674	678	694	705	700	678	735	707	699	720	710
0-21 d	P2	639	653	646	573	634	604	690	686	688	772	693	733
	P3	476	516	496	510	524	517	613	575	594	581	574	578
	Mean	**599**	**614**	**607**	**592**	**621**	**607**	**660**	**665**	**663**	**684**	**662**	**673**
	RMS						**8.471**						
	Main effects	Protein					Feed form				Yeast		
		P_1	P_2	P_3			M	P			0	+	
		698	668	546			607	668			635	640	

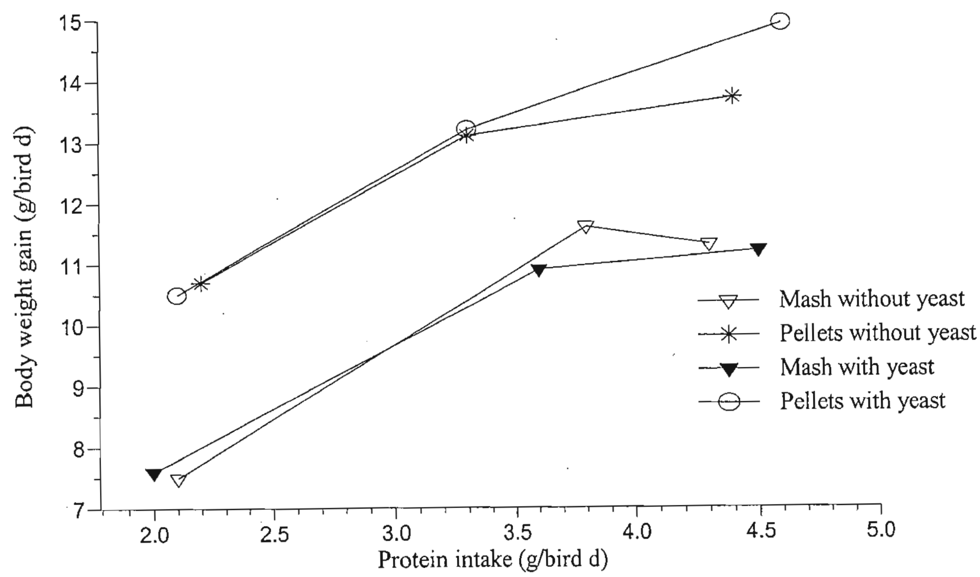

Figure 4.1 *Mean weight gains of broilers fed different feed form with or with out the addition of yeast from 0-7 d of age*

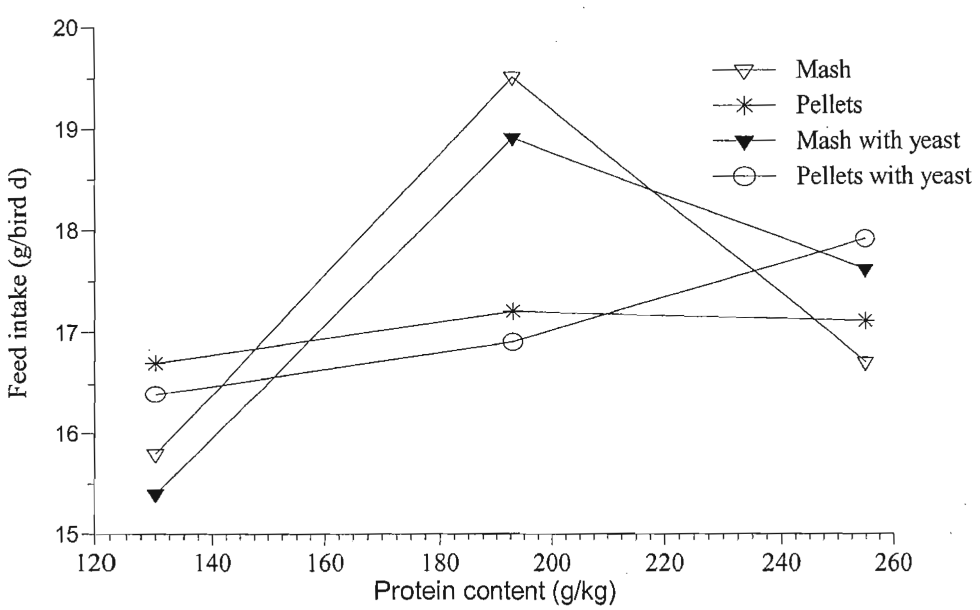

Figure 4.2 *Mean food intake of broilers fed different feed form with or with out the addition of yeast from 0-7 d of age*

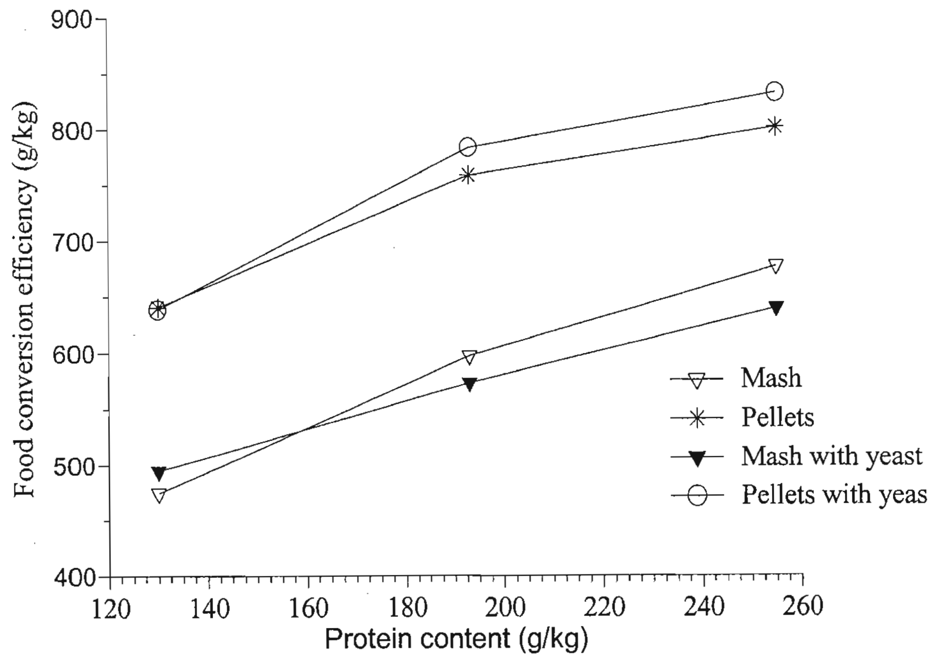

Figure 4.3 *Mean food conversion efficiencies of broilers fed different feed form with or with out the addition of yeast from 0-7 d of age*

4.6 Discussion

The results once again showed improvement in body weight gain with an increase in dietary protein content, which occurred without comparative increase in food intake, illustrating that dietary protein content *per se* has a profound effect on body weight gain. This is in line with the findings of Pesti and Fletcher (1984) who observed an increase in body weight gains as dietary protein content increased, without a proportional increase in food consumption. Even though broiler chickens consumed more of the medium protein feed, the use of high dietary protein level was more efficient. This high food intake but low response as compared to high protein level may be attributed to the fact that the broiler chickens had to eat more food to be able to obtain sufficient protein to grow at their potential, but were unable to consume as much as those birds on the high protein feed. This is in line with the findings of Parson and Baker (1982) who showed that dietary protein level improved FCE.

The significant difference in growth between sexes in response to the increase in dietary protein content indicates that the sexes have different nutritional requirements. This is in accord with the findings of Ajang *et al.* (1993) who observed significant differences between sexes on feeds differing in dietary protein content, with males showing better response. However, in this trial it was the females that showed better performance. It is likely that, because of the higher potential growth rate of the males, the growth rate of the males would soon have exceeded that of the females.

The poor weight gains of the broilers fed mash compared to those on pellets can be attributed to the differences in maintenance requirements of the birds between the two feed forms, as discussed in the previous chapter. Although feeding pellets did not increase food intake there was a significant increase in FCE in all treatments, illustrating that the broilers used food more efficiently when the food was pelleted.

Penz (2002) suggested that the addition of food additives and extra doses of vitamins in the diet could be valuable to young broilers. Yeast was added in this trial as a source of B vitamins. The inability of the yeast to enhance chicken performance can be attributed to the fact that the vitamin + mineral premix used in formulating the feeds supplied adequate amounts of vitamins for growth, and that the yeast provided no other essential nutrient that was not already supplied.

4.7 Conclusions

The overall growth measured in this trial was below the potential of commercial broilers (about 18-20g/bird d). However, as with the previous trial, the highest dietary protein content used gave the best growth rate (15g/bird d), and pellets significantly improved performance compared with mash feeds. The response of chicks to the addition of brewer's yeast had a negative or zero influence on growth, suggesting that the inclusion rate of the standard vitamin and mineral premix was adequate for chick growth.

Chapter 5

The effect of Spirulina, Optivite and conjugated linoleic acid on early performance of broilers

5.1 Introduction

The previous three chapters report the use of dietary protein contents, feed additives, feed form and feeder location in a quest to improve 7 d body weight gain at the Ukulinga research farm. Young broiler chickens did not respond to the addition of antibacterial growth promoters or to other feed additives (vitamins and yeast), and whereas pelleted feeds high in dietary protein content had the most significant beneficial effect on performance, growth rates to 7d in the previous experiments was still not as high as the potential of these chicks. The factor limiting broiler performance during the first week of life therefore remains unclear.

The opportunity arose to make use of three new feed additives that are becoming freely available in South Africa, namely, Spirulina, which is purported to supply additional amounts of protein, vitamins and minerals; a multi-enzyme cocktail (Optivite) containing glucanase, xylanase and phytase, which is purported to improve nutrient digestibility and chicken performance; and conjugated linoleic acid (CLA) which has been reported to improve chick performance.

Broiler feeds are predominantly composed of plant materials, such as cereals and vegetable proteins, and little animal protein is now included. Most of the feed ingredients contain a non-digestible fraction (for example, cellulose, xylose, arabinose, galactonic acid) and some anti-nutritive factors, which reduce food utilisation and overall broiler performance. The effects of these anti-nutritive factors may be severe in young broilers due to the fact that chickens are hatched with insufficient enzymes necessary for the complete digestion of most food components (Noy and Sklan, 1995). Sklan (1995) suggested that young broiler chickens might be limited in the type and amount of enzymes required to be able to utilise high carbohydrate and vegetable protein feeds, thus affecting nutrient digestibility. The effect of these anti-nutritional factors is manifested by depressed nutrient utilisation, accompanied by poor growth (Choct and Annison, 1990). These latter authors suggested that adverse effects could be overcome by the addition of exogenous enzymes. It has also been suggested that enzymes reduce the rate of digestion so that there is less substrate available to support microbial populations in the large intestine (Bedford, 2000). Thus, considerable interest has been shown in the addition of dietary enzymes during the early growing period.

Spirulina is generally regarded as a good source of nutrients, as it is high in vitamins and minerals, as well as protein. Although it is nutritious, very little is known about its nutritive value and use for young broiler chickens. When Ross and Dominy (1990) fed broilers food containing between 0 and 20% Spirulina they observed a significant growth depression with the diet containing 20% Spirulina as early as the first week of life. Similarly, Becker and Venketaraman (1982) reported growth depression in broilers with the use of 5 and 10% levels of Spirulina.

The use of conjugated linoleic acid (CLA) has been suggested as a possible means of attaining desirable carcass fat levels in broilers fed low protein feeds (Aletor, 2003). Cook *et al.* (1993) reported that 0.5% dietary CLA enhanced immune response in chickens. Sell *et al.* (2001) fed young broilers feeds containing 4, 8 and 12% CLA and noted no effect of CLA on weight gain, but a linear decline in food consumption and FCE.

This experiment was conducted to determine the effect of Spirulina, Optivite and dietary conjugated linoleic acid (CLA) on the performance of broilers.

5.2 Materials and methods

5.2.1 Birds and housing

Seven hundred and twenty day old sexed Ross broiler chickens were purchased from National Chicks Farms. They were housed in a brooder house at Ukulinga research farm. The chickens were randomly selected and placed into ninety-six cages, the sexes separate. They were kept in these cages for the duration of the experiment (1 to 21d). Single tier broiler cages measuring 80 x 50cm and two nipple drinkers were used in this trial. Feed troughs were located inside the cages for the first 10 d, after which the troughs were placed outside the cages. Each feeding trough contained a feed saver grid to avoid feed wastage. Each cage was allocated a 5kg feed bin, which was filled with the test feed and then weighed at the beginning of the experiment. Both maximum and minimum temperatures were recorded every day. All birds in each cage were weighed as a group at the start of the trial and also at the end of each week. Mortality was recorded as it occurred. The trial was terminated when the chickens were 21d old.

5.2.2 Diets and treatments

Unmedicated broiler starter crumbles was obtained from Meadow Feeds. The nutritional composition of the feed is shown in Table 5.1. This feed was fed as such, with the addition of two levels of Spirulina (0 and 0.5%), with the addition of two levels of Optivite (0 and 0.5ml/kg) and three levels of CLA (0, 1.25 and 2.5%). The control diet was sampled, and this was analysed for apparent metabolisable energy (AME) and digestible amino acid content. Food was transferred from these bins to the feeding trough when necessary. At the end of each week the food remaining in each trough was returned to the bin, which was then weighed to determine the amount of food consumed by the chickens during the week. Both feed and water were supplied *ad libitum*. The room was heated with a gas space heater. The desired temperature of 29.5^{0}C was maintained throughout the brooder room for the first week.

5.3 Experimental design

The study was conducted as a 2^n factorial design with no blocking. Each treatment was replicated four times, with each group of seven and eight male and female, respectively representing a replicate. The experiment consisted of factorial arrangement of fixed treatment effects consisting of three levels of CLA, two levels of Spirulina, two levels of Optivite and two sexes, giving a 3x2x2x2 factorial design.

Table 5.1 *Chemical composition (g/kg) of the control diet used in this trial*

Nutrient	Quantity
Protein	221
AMEn (MJ/kg)	12.8
TMEn (MJ/kg)	13.2
Dry matter (%)	90.6
Amino acids	
Threonine	8.1
Valine	10.8
Methionine	3.7
Isoleucine	10.3
Tyrosine	5.2
Phenylalanine	11.3
Leucine	19.6
Histidine	5.9
Lysine	12.4
Arginine	12.4

[4]Chemical composition was calculated using Winfeed on as is basis by Feed Evaluation Unit, at University of Natal, 2003

Table 5.2 *Description of dietary treatments used in this trial*

Treatment	Spirulina	Optivite	CLA
1	0	0	0
2	0	0	1
3	0	0	2
4	0	+	0
5	0	+	1
6	0	+	2
7	+	0	0
8	+	0	1
9	+	0	2
10	+	+	0
11	+	+	1
12	+	+	2

5.4 Statistical analysis

The body weights, food intakes and FCE's of all surviving birds were subjected to the analysis of variance using Genstat. Interactions between the dietary treatments were also tested. Treatment means and residual mean squares were obtained using an Analysis of Variance.

5.5 Results

5.5.1 Body weight gain

Body weight at 7 d of age was significantly ($P< 0.05$) improved (1.6g/bird d) by the addition of Optivite (Table 5.3 and Figure 5.1). Slight improvements occurred due to the addition of the combination of Spirulina and Optivite (1.2g/bird d) and the addition of each or in tandem with low levels of dietary CLA. However, their addition with high levels of dietary CLA reduced body weight gain (Table 5.3 and Figure 5.1). The addition of Spirulina and high CLA resulted in reduced gains, with only the addition of the latter being significant ($P < 0.01$) during the first feeding period. At 21 d of age body weight gain of the control group was slightly higher than when feed additives were used either alone or in combination, thus showing that no response occurred to their addition at this age (Table 5.4). There was a significant difference between sexes in body weight gain at 7 d of age, with females gaining more weight than males, but no differences were observed thereafter. There was a significant ($P < 0.05$) effect of the interaction between Optivite x CLA on body weight gain up to 7 d of age, with a decline in the response to Optivite as the level of dietary CLA increased (Figure 5.1).

5.5.2 Food intake

Food intake was slightly increased by the addition of Optivite and its combination with Spirulina (Figure 5.1), while a reduction occurred with all other combinations. The addition of dietary CLA showed an adverse effect on food intake, although only at the high level of its inclusion was it significant ($P< 0.05$). All feed additives caused a reduction in food intake up to 21 d of age (Table 5.4). There were no significant differences in food intake between sexes in either feeding period, nor were there significant interactions between feed additives in food intake at either age group.

Table 5.3 *Main effects and interactions (n = 8) in body weight gain (g/d), feed intake (g/d) and feed conversion efficiency (g gain/kg feed) (FCE) of broilers offered feeds with and without the addition of feed additives to 7 d of age, with SEM and LSD (5%)*

Source			Body weight gain			Feed intake			FCE		
Spirulina	Optivite	CLA	M	F	M/F	M	F	M/F	M	F	M/F
0	0	0	13.6	15.4	14.5	21.3	24.6	22.9	641	624	633
0	0	1	13.6	15.5	14.6	20.3	23.6	22.0	670	657	664
0	0	2	14.5	13.8	14.1	22.2	21.6	21.9	650	632	641
0	+	0	14.8	17.5	16.1	22.1	25.0	23.5	667	703	685
0	+	1	13.8	15.7	14.7	21.8	23.3	22.6	633	674	654
0	+	2	13.0	15.6	14.3	21.4	23.4	22.4	605	669	637
+	0	0	13.0	15.6	14.3	21.7	23.6	22.6	600	662	631
+	0	1	14.2	15.9	15.0	21.7	23.2	22.4	657	685	671
+	0	2	12.5	15.4	14.0	21.2	23.2	22.2	593	665	629
+	+	0	15.3	16.1	15.7	22.5	24.3	23.4	680	663	672
+	+	1	13.5	15.9	14.7	20.8	23.2	22.0	647	687	667
+	+	2	13.4	15.1	14.2	23.8	20.9	22.3	642	632	637
RMS				1.666			2.313			2766	
LSD				1.82			2.14			74.1	
Main effect				0	+		0	+		0	+
Spirulina (n= 48)				14.7	14.6		22.5	22.5		652	651
Optivite (n=48)				14.4	15.0		22.3	22.7		645	659
			0	1	2	0	1	2	0	1	2
CLA (n = 32)			15.1	14.8	14.2	23.1	22.2	22.2	655	664	636

CLA = conjugated linoleic acid, 1 = 1.25% CLA, 2 = 2.5% CLA, M/F = mean, RMS = residual mean square

Table 5.4 *Main effects and interactions (n = 8) in body weight gain (g/d), feed intake (g/d) and feed conversion efficiency (g gain/kg feed) (FCE) of broilers offered feeds with and without the addition of feed additives to 21 d of age, with RMS and LSD (5%)*

Source			Body weight gain			Feed intake			FCE		
Spirulina	Optivite	CLA	M	F	M/F	M	F	M/F	M	F	M/F
0	0	0	33.2	33.6	33.4	51.8	53.5	52.6	641	628	634
0	0	1	31.3	32.3	31.8	49.5	52.4	50.9	632	615	623
0	0	2	33.3	30.2	31.7	53.4	49.2	51.3	623	615	619
0	+	0	32.6	31.9	32.2	52.2	52.2	52.2	623	610	616
0	+	1	31.9	33.4	32.6	51.1	52.8	51.9	624	633	628
0	+	2	30.6	34.9	32.8	48.5	54.4	51.5	631	642	636
+	0	0	30.9	31.7	31.3	51.0	51.8	51.4	606	611	609
+	0	1	31.0	33.0	32.0	50.2	51.9	51.0	618	635	627
+	0	2	30.3	31.9	31.1	48.7	52.1	50.4	622	612	617
+	+	0	31.8	31.4	31.6	51.4	50.4	50.9	619	620	619
+	+	1	31.1	33.1	32.1	50.2	52.3	51.3	619	632	626
+	+	2	31.0	31.4	31.2	48.6	50.6	49.6	636	621	628
RMS				5.071			8.609			428.9	
LSD				3.17			4.14			29.19	
Main effect				0	+		0	+		0	+
Spirulina (n = 48)				32.4	31.5		51.7	50.8		626	621
Optivite (n = 48)				31.9	32.1		51.3	51.2		621	626
			0	1	2	0	1	2	0	1	2
CLA (n = 32)			32.1	32.1	31.7	51.8	51.3	50.7	620	626	625

5.5.3 Food conversion efficiency

There was a positive response in FCE due to the addition of feed additives, except when Spirulina and its combination with high levels of dietary CLA were added to the feed at 7 d of age (Figure 5.2), but none of these differences was significant. The response to feed additives at 7 d of age decreased as the dietary CLA increased (Figure 5.2). However, no response was observed due to the addition of feed additives at 21 d of age. In fact, their use at this age resulted in a decline in FCE (Table 5.4). Females had a higher ($P < 0.05$) FCE than males at 7 d of age, but no significant differences were observed thereafter.

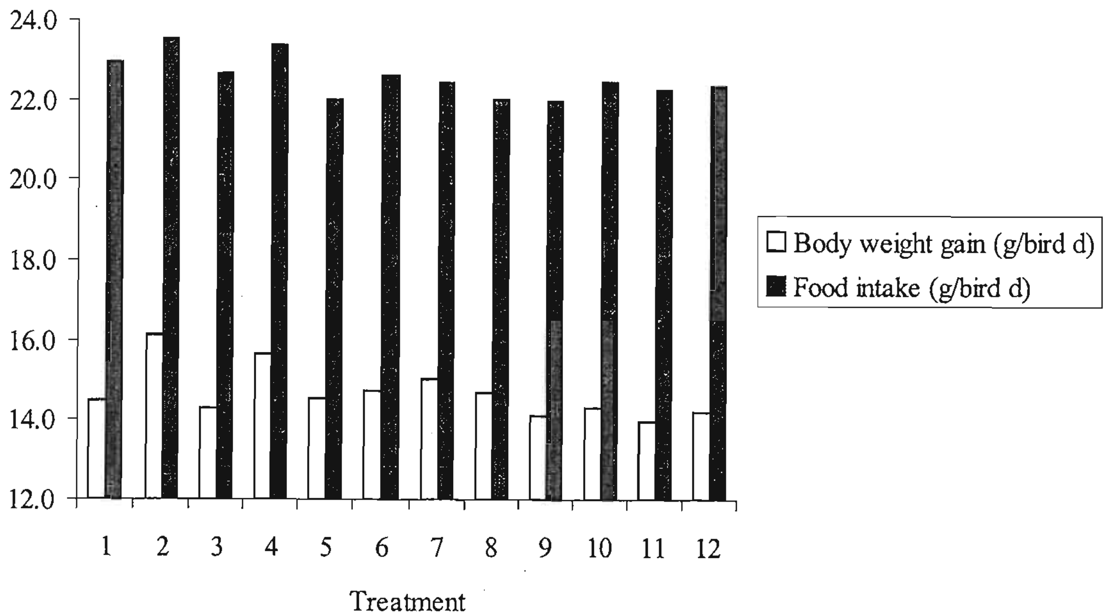

Figure 5.1 *Mean weight gains and food intake of broilers fed diets with or without the addition of additives from 0-7 d of age. See Table 5.2 for description of treatments.*

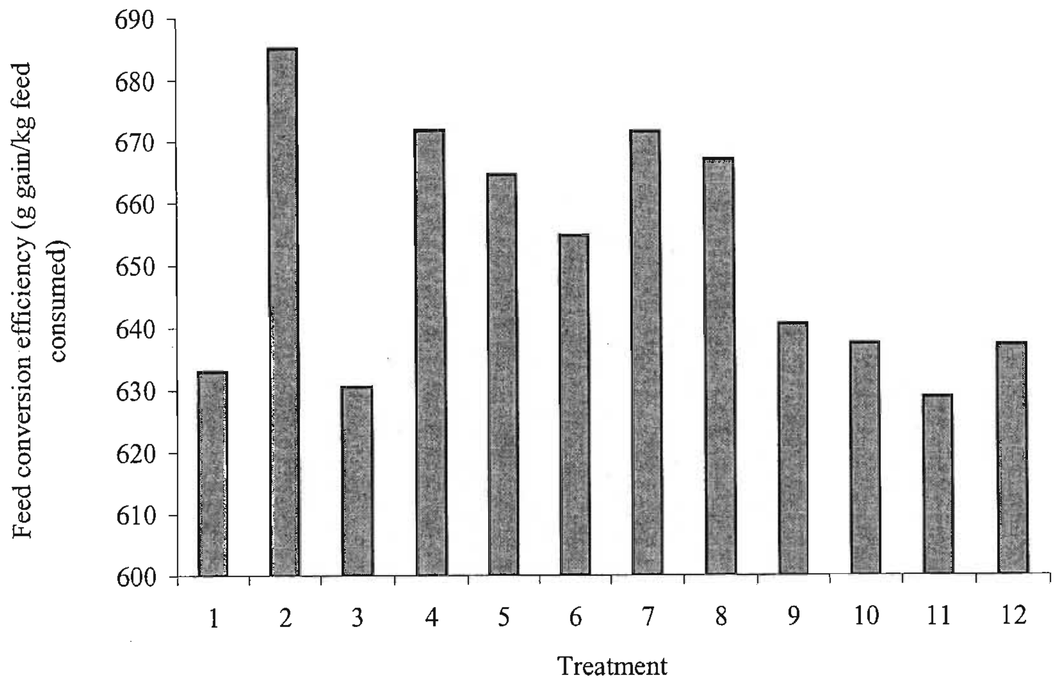

Figure 5.2 *Mean food conversion efficiency of broilers fed diets with or without the addition of additives from 0-7 d of age. See Table 5.2 for the description of treatments*

5.6 Discussion

This experiment was conducted to investigate whether food intake, weight gain and FCE in young broiler chickens could be improved by the addition of Spirulina, Optivite or CLA. Accordingly, unmedicated broiler starter crumbles were fed together with the addition of feed additives either alone or in tandem to day old broilers housed in the brooder room.

The exogenous enzymes are added to the feed in order to improve its digestibility, thus making nutrients available for growth of the broiler chickens. The results of this experiment showed that the addition of a composite enzyme (Optivite) significantly improved body weight gain without any significant improvement in either food intake or FCE, but both these latter variables were slightly improved above the control feed up to 7 d of age, but failed to show improvement up to 21 d of age. This significant improvement in body weight gain is in accordance with the findings of Bustany (1996) and Alam *et al.* (2003). These authors claimed that the improved food utilisation when the broiler chickens were given feeds supplemented with enzymes was responsible for the increased body weight gain for broiler chickens on similar dietary nutrient concentration. Moreover, they suggested that the addition of exogenous enzymes increased digestibility of nutrients and partially degraded the cell wall of the food, thus, resulting in increased performance.

The decline in food intake to 21d when Optivite was added is in agreement with the findings of Richter *et al.* (1995), where food intake decreased with the addition of enzymes due to the fact that those broiler chicken offered feeds with exogenous enzymes obtained their nutrient requirements by consuming less food than the broiler chickens on control feed. Furthermore, this may have occurred due to the fact that, as the broiler chickens increase in age, their secretion of endogenous enzymes increases (Cook *et al.*, 2000), thus reducing the response to the addition of exogenous enzymes.

The depressed body weight gain and FCE observed with the addition of high levels of dietary CLA in this trial is consistent with the findings of Szymczyk *et al.* (2001). However, dietary CLA has been reported as being a potent inhibitor of body fat accumulation in chickens (Pariza *et al.*, 1996) and to act as a fat-to-lean repartitioning agent in growing pigs (Dugan *et al.*, 1997). Therefore, it would be expected that these alterations would result in improved performance. However, the CLA may have stimulated fatty acid oxidation, and thus enhanced the metabolic rate of broiler chickens (Szymczyk *et al.*, 2001). Furthermore, since dietary CLA plays an important role in lean-to-fat deposition which is both a protein and energy demanding process (Wiseman, 1986), higher food intake but lower body weight gain and FCE (in terms of body weight gain) may have occurred as a result of high nutrient demands for lean meat production.

The insignificant depression in growth due to the addition of Spirulina is in accordance with the findings of Yoshida and Hoshii (1980) who found no significant growth depression with 3 to 5% of Spirulina. However, these results are in contrast with the findings of Becker and Venkataraman (1982) who reported depressed growth only when dietary Spirulina content exceeded 5%. This suggests that the quality of the Spirulina may be a factor in its effect as a feed additive. In fact, the inability of broiler chickens to respond to additional levels of protein, vitamins and trace minerals obtained as a result of addition of Spirulina over that of the control group may have been because the maximum threshold of these nutrients may have been reached in the basal feed. Moreover, Spirulina did not appear to decrease food intake, as has been reported by Combs (1952), who observed that broiler chickens on feeds containing Spirulina suffered from impacted beaks, which then interfered with their food intake, thus adversely affecting their performance.

When Optivite and high levels of CLA were combined, the significant decline in body weight gain that resulted might have been due to more nutrients being available for lean meat growth and less for fat growth, resulting in high muscle growth while reducing weight gain. Chemical analyses were not conducted on the broilers at the end of the trial, so it is not possible to substantiate this, however.

5.7 Conclusions

Growth of the broiler chickens was improved by the addition of the enzyme cocktail, thus indicating that its inclusion in the feed did overcome a limitation to chick performance, although the basal feed was not the same as had been used in the previous trials. Neither Spirulina nor dietary CLA improved performance, hence it could be concluded that no limiting resource was obtained due to their supplementation.

Summary

The ability of broiler chickens to achieve their genetic potential is affected by the quality of the feed on offer and the prevailing environmental conditions in the house in which they are kept. Thus, an understanding of the requirements of the broiler chicken at each stage of growth is essential if performance is to be maximised. Performance during the first week of life could be regarded as being the most important stage of the growth of broiler chickens. It is the foundation that determines how well the chickens will perform up to harvesting age. This period in the growth of a broiler chicken is traumatic in that important changes occur in the physiological functioning of the bird at this time, and chicks lack some of the enzymes that are important for the digestion of the exogenous food (Noy and Sklan, 1995). Therefore it is important that comprehensive studies be conducted that will improve our understanding of how performance can be optimised. The objective of this study was to improve body weight gain during the first week of life of broiler chickens at Ukulinga research farm. The possible constraints were examined, and these were classified as being due to the feed composition, to the feed form, and to a peculiarity of the housing system, namely, that the feed troughs were not easily accessible to chicks in the fist week of life. Four experiments were conducted in this study in a quest to improve 7-d body weights, which had been consistently below the potential for the strains used.

The performance of the broiler chickens improved from one experiment to the next. However, the performance of the broiler chickens in the first experiment was below that normally obtained at Ukulinga, and considerably below the potential growth rate of commercial broiler chickens. This experiment was used as the base for subsequent experiments. Although no response occurred due to the addition of feed additives, except when enzymes were added to the feed, it was observed that dietary protein content consistently influenced the performance of the broiler chickens. This was noted by the increasing performance of the broiler chickens as the dietary protein was increased. However, the broiler chickens did not make utmost use of the high protein level in the first trial, as no significant improvements were observed between this and medium protein level. It appeared that these chickens obtained their requirement just above the medium protein level, but more experiments were needed to determine the exact level. The improved performance with increased dietary protein content obtained in this study concurred with the reports in the literature that protein is the most important nutrient for

the growth of broilers (Smith and Pesti, 1998), and that the requirements of the modern broiler chickens are greater than those of the broilers of the past. Hence, they need high levels of protein to be included in their feeds.

Although it appeared that protein was one of the major constraints to performance, the form of the feed (mash) normally offered to the chickens at Ukulinga proved to be another constraint. This was proved by the significant improvements in body weight and FCE when the feed was pelleted. The broiler chickens offered mash feed tended to eat more food than those on pelleted feeds. This occurred due to the high maintenance requirements when they are offered mash, resulting in less food being available for production. Another reason that pellets were more successful than mash feeds is that chickens have a tendency to consume bigger particles first because of their preference for bigger feed particles, and if they are fed mash feed they will select the feed ingredients with the bigger particles, which means they may not consume more of the fine ingredients (like amino acids and minerals), thus, adversely affecting their performance.

When broiler chickens arrive at Ukulinga at the start of the experiment, they are normally supplied with food that is placed on a piece of paper on the floor of the cage, so that they can have access to feed until they are able to jump up into the feeders. However, young broiler chickens tend to scratch this feed, thus adding to feed wastage. The problem of feed accessibility was corrected by locating the feeding troughs inside the cages until broiler chickens were 10 d of age

In the light of the results from this study, feeding 0-21 d old broiler chickens feeds in mash form is not the ideal way of achieving maximum output. Feeding them this form of feed deprives them of the ability to express their genetic potential. When the feeds were pelleted, improvements in growth rate up to 3g/bird d and 7.8g/bird d were obtained at 7 and 21 d of age, as well as a substantial improvement in feed utilisation occurred. These results indicate that pellets are more suitable for growth of broiler chickens at any stage of growth. However, the performance of broilers obtained in this study is still not the true reflection of the growth that can be obtained at Ukulinga research farm. More studies are needed that will evaluate ways of further improving the development of the broiler chickens, with the effect of environmental temperature being one of the main factors that should still be investigated.

References

Alam, M. J., Howlider, M. A. R., Pramanik, M. A. H. and Haque, M. A. (2003) Effects of exogenous enzyme in diet on broiler performance. *International Journal of Poultry Science,* **2 (2):** 168-173

Ajang, O. A., Prijono, S. and Smith, W. K. (1993) Effect of dietary protein content on growth and body composition of fast and slow feathering broiler chickens. *British Poultry Science,* **34:** 73-91

Aletor, V. A., Eder, K., Becker, K., Paulicks, B.R., Roth, F. X. and Roth Maier, D. A. (2003) The effects of conjugated linoleic acida or an α-glucosidase inhibotor on tissue lipid concentrations and fatty acid composition of broiler chicks fed a low protein diet. *Poultry Science,* **82:** 796-804

Allred, J. B., Fry, E. R., Jensen, L.S. and McGinnis, J. (1957) Studies with chicks on the improvement in nutritive value of feed ingredients by pelleting. *Poultry Science,* **36:** 1284-1289

Almquist, H. J. and Grau, C. R. (1943) Growth promoting activity of betaine in the chick. *Journal of Biological Chemistry*, **149:** 575-576

Alimquist, H. J. and Grau, C. R. 1944. Interrelationship of methionine, choline, betaine and asenocholine in the chick. *Journal of Nutrition* **27:** 263-269

Baker, D. H. and Han, Y. (1994) Ideal amino acid profile for chicks during the first three weeks posthatching. *Poultry Science*, **73:** 1441-1447

Bartov, I. (1995) Differential effect of age on metabolisable energy content of high protein-low energy and low protein-high energy diets in young broiler chicks. *British Poultry Science*, **36:** 631-643

Becker, E. and Venkataraman, L. (1982) In: Biotechnology and Exploitation of algae- The Indian approach. Germany Agency for Technical Cooperation, Eschborn, West Germany, pp. 96-176

Bedford, M. R. (2000) Removal of antibiotic growth promoters from poultry diets: implications and strategies to minimise subsequent problems. *World's Poultry Science Journal*, **56:** 347-365

Bird, H. R. (1968) Effectiveness of antibiotics in broiler feeds. *World's Poultry Science Journal,* **24:** 309-312

Bolton, W. (1960) The digestibility of mash and pellets by chickens. *Journal of Agric Science*, **55:** 141-142

Britton, W. M. (1991) Dietary sodium and chloride for broiler chick growth. *Poultry Science*, **70:** 1-18

Bunyan, J., Jeffries, L., Sayers, J. R., Gulliver, A. L. and Coleman, K. (1977) Antimicrobial substances and chick growth promotion: the growth promoting activity of antimicrobial substances including fifty-two used either in therapy or as dietary additives. *British Poultry Science*, **18:** 283-294

Bustany, Z. (1996) The effect of pelleting on enzyme supplementated barley based diet. *Feed Science Technology*, **58:** 283-288

Calet, C. (1965) The relative value of pellets versus mash and grain in poultry. *World's Poultry Science Journal*, **21:** 23-52

Cahaner, A, Dunnington, E. A., Jones, D. E., Cherry, J. A. and Siegel, P. B. (1987) Evaluation of two commercial broiler male lines differing in efficiency of feed utilization. *Poultry Science,* **66:** 1101-1110

Carew, L. B., Machemmer, L. H., Shar, R. W. and Foss, D. C. (1972) Fat absorption in a very young chick. *Poultry Science,* **51:** 738-742

Charles, D. R. (1986) Temperature for broilers. *World's Poultry Science Journal,* **42:** 249-258

Choct, M. and Annison, G. (1990) Anti-nutritive activity of wheat pentosans in poultry diets. *British Poultry Science,* **31:** 800-810

Combs, G. F. (1952) Algae (Chlorella) as a source of nutrients for the chicks. *Science, New York,* **161:** 453-454

Cook, M. E., Miller, C. C., Park, Y. and Pariza, M. W. (1993) Immune modulation by altered nutrient metabolism: nutritional control of immune-induced growth depression. *Poultry Science,* **72:** 1301-1305

Cook, M. E., Drake, B. M. and Pierson, E. E. (2000) Effects of avizyme on laying hen performance. *Poultry Science,* **79 (7):** Abstract

Dafwang, I. I., Cook, M. E. and Sunde, M. I. (1987) Interaction of dietary antibiotic supplementation and stocking density on broiler chick performance and immune response. *British Poultry Science,* **28:** 47-55

Damron, B. L., Johnson, W. L. and Kerry, L. S. (1986) Utilization of sodium and sodium bicarbonate by broiler chicks. *Poultry Science,* **65:** 782-785

Deaton, J. W., Branton, S. L, Simmons, J. D. and Lott, B. D. (1996) The effect of brooding temperature on broiler performance. *Poultry Science,* **75:** 1217-1220

Devegowda, G., Aravind, B. I. R. and Morton, M. G. (1994) Boitechnology in the feed industry. Proceedings of Alltechs 13th Annual Symposium. Nottingham University Press, pp. 205-215

Douglas, J. H., Sullivan, T. W., Bond, P. L., Struwe, F. J., Baire, J. G. and Robinson, L. G (1990) Influence of grinding, rolling and pelleting on nutritional value of grain sorghums and yellow corn for broilers. *Poultry Science,* **69:** 2150-2156

Dugan, M. E. R., Aalhus, J. L., Schaefer, A. L. and Kramer, J. K. G. (1997) The effect of conjugated linoleic acid on fat to lean repartitioning and feed conversion in pigs. *Canadian Journal of Animal Science*, **77:** 723-725

Edwards, H. M. (1962) Observation on feeding cholic acid to broilers. *Poultry Science*, **41:** 340-341

Emmans, G. C. (1981) A model of the growth and feed intake of ad libitum fed animals, particulary poultry. In: Computers in Animal production, Occasional Publication No. 5

Emmans, G. C. and Fisher, C. (1986) Problems in nutritional theory, In: Fisher, C. and Boorman, K. N. (Ed.) Nutrient requirements of poultry and Nutritional Research: Poutry Science Symposium Series, No 19, pp, 9-39 (London, Butterworths)

Emmans, G. C. and Oldham, J. D. (1988) Modelling of growth and nutrition in different species. In: Modelling of Livestock Production Systems, Ed. Karver, S. and Arendonk J. A. M. (1988)

Emmans, G. C., Fisher, C. and Gous, R. M. (2002) EFG Broiler Growth Model. University of Natal, South Africa

Freeman, C. P. (1979) The tryptophan requirement of broiler chicks. *British Poultry Science,* **20:** 27-37

Foster, W. H. and Stevenson, M. H. (1983) The interaction of food additives and protein content in broiler diets. *British Poultry Science,* **24:** 455-462

Genstat executable. (2002) Genstat statistical software release 6.1. Lawes Agricultural Trust

Gous, R. M., Emmans, G. C., Broadbent, L. A. and Fisher, C. (1990) Nutritional effects on growth and fatness of broilers. *British Poultry Science*, **31:** 495-505

Griffin, R. M. (1980) The response of cage reared cockerels to dietary medication with growth promoters, 1. Size and consistency of the response. *Poultry Science*, **59:** 412-416

Griffiths, L., Leeson, S. and Summers, J. F (1977) Fat deposition in broilers: effect of dietary energy to protein balance and early life restriction on productive performance and abdominal fat pad size. *Poultry Science*, **56:** 638-646

Han, Y. and Baker, D. H. (1993) Effects of excess methionine or lysine for broilers fed a corn-soybean meal diet. *Poultry Science,* **72:** 1070-1074

Hays, V. W. (1969) Biological basis for the use of antibiotics in livestock production. The use of drugs in animal feeds. National Academy of Sciences, Pub. 1697

Heywang, B. W. and Morgan, R. B. (1944) A comparison of pelleted and unpelleted all-mash diet for growing chickens. *Poultry Science*, **23:** 16-20

Hinds, F. C. and Scott, H. M. 1958. Age of chick-A factor in the response to pelleted corn. *Poultry Science* **37:** 189-192

Hulan, H. W., Proudfoot, F. G., Ramey, D. and McRae, K. B. (1980) Influence of genotype and diet on general performance and incidence of leg abnormalities of commercial broilers reared to roaster weight. *Poultry Science,* **59:** 748-757

Hunchar, J. G. and Thomas, O. P. (1976) The tryptophan requirement of 4-7 week broiler. *Poultry Science*, **55:** 379-383

Iji, P. A., and Tivey, D. R. (1998) Natural and synthetic oligosaccharides in broiler chicken diets. *World's Poultry Science Journal,* **54:** 129-143

Jensen, L. S., Merill, L. H., Reddy, C. V. and Mcginnis, J. (1962) Observations on eating patterns and rate of food passage of birds fed pelleted and unpelleted diets. *Poultry Science*, **41:** 1414-1419

Jin, G. (2002) Betaine helps poultry cope with heat stress. Finfeeds International Pte Ltd. United Kingdom

Katongole, J. B. D. and March, B. E. (1980) Fat utilization in relation to intestinal fatty acid binding protein and bile salts in chicks of different genetic sources. *Poultry Science,* **59:** 819-827

Kennedy, D. G., Rice, D. A., Bruce, D. W., Goodall, E. A., and McIroy, S.G. (1992) Economic effects of increased vitamin E supplementation of broiler diets on commercial broiler production. *British Poultry Science,* **33:** 1015-1023

Kubena, L. F., Chen, T. C., Deaton, J. W. and Reece, F. N. 1974. Factors affecting the quality of abdorminal fat in broilers.3. Dietary energy levels. *Poultry Science* **53:** 974-978

Kubena, L. F., Deaton, J. W., Reece, F. N. and May, J. D. (1972) Body composition of chicks as influenced by environmental temperature and selected dietary factors. *Poultry Science,* **51:** 517-522

Kilburn, J. and Edwards, Jr. H. M. (2001) The response of broilers to feeding of mash or pelleted diets containing maize of varying particle sizes. *British Poultry Science,* **42:** 484-492

Leeson, S. and Zubair, A. K. (2000) Digestion in poultry I protein and fats. Novus International, Canada

Leroy, A. M. 1961. Utilization of pelleted diets by young chicks. Proceedings 2nd Symposium on energy metabolism. Waseningen, 11-15 September 1961, 285-290

Lott, B. D., Day, E. J. and Deaton, J. D. (1992) The effect of temperature, dietary energy level, and corn particle size on broiler performance. *Poultry Science,* **71:** 618-624

May, J. D. and Lott. B. D. (2000) The effect of environmental temperature on growth and feed conversion of broilers to 21 days of age. *Poultry Science,* **79:** 669-671

McGinnis, J., Norris, L. C. and Heuser, G. F. (1942) Effect of ethanolamine and betaine on perosis in chicks. *Experimental Biology and Medicine*, **51:** 293-294

McNaughton, J. L. (1984) Factors affecting pelleting response. 1. Influence of dietary energy in broiler starter diets. *Poultry Science*, **63:** 682-685

Moran, E. T. (1987) Effect of pellet quality on the performance of meat birds. In: Recent Advances in Animal nutrition, Butterworths, London, 89-108

Morris, T. R. and Njuru, D. (1990) Protein requirement of fast and slow growing chicks. *British Poultry Science*, **31:** 803-809

Morris, T. R., Gous, R. M. and Fisher, C. (1999) An analysis of the hypothesis that amino acid requirements for chicks should be stated as a proportion of dietary protein. *World's Poultry Science Journal*, **55:** 8-21

Murakami, A. E., Watkins, S. E., Saleh, E. A., England, J. A. and Waldroup, P. W. (1997) Estimation of the sodium and chloride requirements for the young broiler chick. *Journal Applied Poultry Research*, **6:** 155-162

National Research Council (1984) Nutrient requirements of poultry 8th rev. edition. National Academy Press, Washington, DC.

National Research Council (1994) Nutrient requirements of poultry 9th rev. edition. National Academy Press, Washington, DC.

Nir, I., Melcion, J. P. and Picard, M. (1990) Effect of particle size of sorghum grain on feed intake and performance of young broilers. *Poultry Science*, **69:** 2177-2184

Nir, I., Hillel, R., Sheft, G. and Nitsan, Z. (1994a) Effect of grain particle size on performance. 2. Grain texture interactions. *Poultry Science*, **73:** 781-791

Nir, I., Sheft, G. and Aaron, Y. (1994b) Effect of particle size on performance. 1. Corn. *Poultry Science*, **73:** 45-49

Nir, I., Twina, Y., Grossman, E. and Nitsan, Z. (1994b) Quantitative effects of pelleting on performance, gastrointestinal tract behaviour on meat type chickens. *British Poultry Science*, **35:** 589-602

Nir, I., Hillel, R., Ptichi, I. And Sheft, G. (1995) Effect of particle size on performance. 3.Grinding pelleting interactions. *Poultry Science*, **74:** 771-783

Noy, Y. and Sklan, D. (1995) Digestion and absorption in young chick. *Poultry Science*, **74:** 366-373

Noy, Y and Sklan, D. (1997) Posthach development in poultry. *Applied Poultry Research*, **6:** 344-354

Oviedo-Rondon, E. O., Murakami, A. E., Furlan, A. C., Moreira, I. And Macarit, M. (2001) sodium and chlorine requirements of young chickens fed Corn-soyabean diets (One to twenty-one days of age). *Poultry Science*, **80:** 592-598

Pariza, M. W., Park, Y., Cook, M. Albright, K. and Liu, W. (1996) Conjugated linoleic acid (CLA) reduces body fat. FASEB *Journal,* 10: A560 (Abstract)

Parson, C. M., and Baker, D. H. (1982) Effect of dietary protein level and monensin on performance of chicks. *Poultry Science,* **61:** 2083-2088

Peisker, M (1999) Amino acid profiles for poultry. In: recent Developments in Poultry Nutrition 2. Eds. Wiseman, J and Garnsworthy, P. C. Nottingham, University press. Page 21-23

Peebles, E. D. and Brake, J. (1985) Relationship of dietary ascorbic acid to broiler breeder performance. *Poultry Science,* **64:** 2041-2048

Penz, A. M. Jr. (2002) Recent advances in broiler nutrition. Nutec 4th International Poultry Symposium, South Africa

Pesti, G. M. and Fletcher, D. L. (1984) The response of male broiler chickens to diets with various protein contents during the growing and finisher phases. *British Poultry Science,* **25:** 415-423

Pinchasov, Y. (1991) Relationship between the weight of the hatchling eggs and subsequent early performance of broiler chicks. *British Poultry Science*, **32:** 109-115

Pinchasov, Y. and Noy, Y. (1993) Comparison of posthatch holding time and subsequent early performance in broiler chicks and turkey poults. *British Poultry Science,* **34:** 111-120

Reece, F. N., Lott, B. D. and Deaton, J. W. (1986a) The effect of environmental temperature and corn particle size on response of broilers to pelleted feed. *Poultry Science*, **65:** 636-641

Reece, F. N., Lott, B. D. and Deaton, J. W. (1986b) The effect of hammer mill screen size on ground corn particle size on response of broilers to pelleted feed. *Poultry Science*, **65:** 1257-1261

Richter, G., Lemser, A. and Muller, A. (1995) Is enzyme feeding beneficial in broiler feeding? Muhle + Mischfutter technik, 131(39): 546-547. In Poultry Abstract, 1995, 21:5

Rose, E. and Dominy, W. (1990) the nutritional value of dehydrated, blue-green algae (*Spirulina plantensis)* for poultry. *Poultry Science*, **69:** 794-800

Rosen, G. D. (1995) Antibacterials in poultry and pig nutrition. In: Biotechnology in animal feeds and animal feeding (Wallace, R. J. and Chesson A. Eds, VCH Verlagsgesellschaft), pp. 143-172

Ross, E. and Dominy, W. 1990. The nutritional value of dehydrated, blue-green algae (*Spirulina plantesis*) for poultry. *Poultry Science* **69:** 794-800

Savory, C. J. (1974) Growth and behaviour of chicks fed on pellets or mash. *British Poultry Science*, **15:** 281-286

Shanawany, M. M. (1987) Hatchling weight in relation to egg weight in domestic birds. *World's Poultry Science Journal,* **43:** 107-115

Sell, J. L., Jin, S. and Jeffrey, M. (2001) Metabolisable energy value of conjugated linoleic acid for broiler chicks and laying hens. *Poultry Science,* **80:** 209-214

Sklan, D. (2001) Development of the digestive tract of poultry. *World's Poultry Science Journal,* **57 (4):** 415-428

Sklan, D., Melamed, D. and Friendman, A. (1994) The effect of varying levels of dietary vitamin A on immune response. *Poultry Science,* **73:** 843-847

Smith, E. R. and Pesti, G. M. (1998) Influence of broiler strain cross and dietary protein on performance of broilers. *Poultry Science,* **77:** 276-281

Smith, E.R., Pesti, G. M., Bakalli, R. I., Ware, G. O. and Menten J. F. M. (1998) Further studies on the influence of genotype and dietary protein on the performance of broilers. *Poultry Science,* **77:** 1678-1687

Swatson, H. K., Gous, R. M. and Iji, P. A. (2000) Effect of dietary energy to protein ratio on performance of broilers. *South African Journal of Animal Science,* **30:** 136-137.

Szymczyk, B., Pisulewski, P. M., Szczurek, W. and Hanczakowski, P. (2001) Effects of conjugated linoleic acid on growth performance, feed conversion efficiency, and subsequent carcass quality in broiler chickens. *British Poultry Science,* **85:** 465-473

Underwood, E. J. and Suttle, N. F. (1999) The mineral nutrition of livestock 3rd edition. CAB International, London

Visek, W. J. (1978) The mode of growth promotion. *Journal of Animal Science.* 46: 1447-1469

Wilson, H. R. (1991) Interrelationship of egg size, chick size, posthatching growth, and hatchability. *World's Poultry Science Journal,* 47: 5-17

Wiseman, J. (1986) High energy diets for poultry- Effect of diet composition on performance and carcass quality. In: Recent Advances in animal nutrition 2001, pp. 87-106

Wiseman, J. (1984) Fats in animal nutrition. Butterworths, London

Yoshida, M. and Hoshii, H. (1980) Nutritive value of spirulina, green algae, for poultry feed. *Japanese Poultry Science*, **17**: 27-30

Ziggers, D. (2003) Antioxidants and MOS feature at Alltech's lecture tour. Feed Technology, **7.1**: 20-21