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The adding of fats to poultry diets and additional poultry feeding behaviour phenomena

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The Adding of Fats to Poultry Diets,

And Additional Poultry Feeding Behaviour Phenomena

by

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Abstract

This study investigated 1) the effect of different fat levels of diets offered in a free-choice feeding regime on feed selection by broiler chicks aged from 1 to 12days; 2) the effect of gradual and sudden changes of diet on broiler performance; 3) the effect of free choice feeding on high (8.0%) and low (4.6%) fat diets by male broilers on diet selection preference; 4) the effect of high and low fat diets on performance of male broiler chickens grown to 30 days old; 5) male broiler chicks feeding preferences with particular respect to birds using colour cues; 6) effect of wet and dry crumb diets given in a free choice selection regime on feeding preference of male broilers from 3 to 7 days old; 7) the effect of the physical form of diet on feeding preference of male broiler chicks; 8) the effect of supplementation of garlic powder as flavour to the starter crumb diet on feeding preference of male broiler chicks; 9) the effect of supplemental fat offered separately on the feeding preference of chicks given a free choice selection regime; 10) the effect of different levels of fat and protein on broiler chick preferences and performances; and 11) broiler performance and carcass composition as affected by supplemental fat at different periods.

The broiler chicks consumed significantly more weight of an 8.0% fat diet than from 4.6% and 6.0% fat diets during the first 6 days post-hatch of a free-choice feeding regime. However, birds' preferences changed during the next 6 days of the experiment. The birds consumed more from 4.6% and 6.0% fat diets than from the 8.0% fat diet.

The present study found, in line with the literature, that gradual change feeding offers no advantage in terms of broiler performance, and that a sudden change in diet was easier to effect in commercial poultry production than was a gradual change.

Supplemental fat significantly reduced feed intake when broilers were fed a diet containing 2% more fat than recommended by the National Research Council (NRC) for 1- to 30-day-old chicks. Body weight was affected negatively but not significantly.

The colour of the feed given initially led to significant preferences in broiler chicks. Chicks given feed of one colour tended to prefer food of the same colour thereafter.

Chicks preferred wet feed to undiluted feed. Feed intake was increased significantly by addition of 1.8 parts of water to 1 part dry food. The broiler chicks preferred the wet diet although they had not been exposed to a wet diet before. Other water consumption by broiler chicks decreased after they had been given a wet diet.

The chicks showed a preference for a crumb diet compared with a pellet diet. They preferred an unflavoured diet compared with a garlic flavoured diet.

When the fat was offered as free choice in separate troughs beside a control diet, chicks significantly failed to consume supplemental fat. Thus, although they preferred high-fat feed, they failed to supplement low fat feed by eating pure fat.

Feed intake, body weight, body weight gain, feed conversion ratio, dressing percentage, carcass composition, body components and behavioural parameters (feeding and drinking) did not show any significant difference when early diet content was manipulated in terms of protein to fat ratios.

Fat added at 1% and 3%, higher than recommended for broiler diets had no negative effect on broiler performance or carcass quality. The present study suggests dietary fat regimens may affect body weight and feed intake, but do not significantly affect carcass quality when the broilers are at marketing age.

In summary, results of the present study suggest that broiler chicks prefer high fat diets during the first week of the post-hatch period. Such early high-fat diet does not seem to adversely affect broiler chicken carcass quality or in other ways impair the birds.

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Chapter 1: General Introduction

In all modern broiler breeds of fowl the rate of meat production has been greatly increased over the past 50 years. The main factors that have been responsible for this increase have been intensive breeding programmes, improvements in nutrition and management, and improvements in disease resistance and control.

Poultry production costs have dramatically fallen as a result of the improvements in every aspect of broiler production and particularly feed improvement, which accounts for more than 70% of poultry production cost (Adloph 1971, 1976; Bonzer and Plumart 1976; Pym and Nicholl 1979; Forbes 1986; Saleh *et al.*, 2004a, 2004b).

Due to high feed costs, seemingly small improvements in the conversion of feed to meat can result in substantial increases in profits for producers. Although broiler nutrition and feeding have been intensively studied over the past 5 decades, there is still room for improvement.

One of the most effective ways to reduce feed cost is to improve food efficiency by increasing meat production per unit of feed consumed. One very effective way to improve feed conversion is through breeding. This includes selection within strains to achieve genetic gain over time, and testing and selecting breeds or strains for crossing to take advantage of heterosis, but this way needs time (El-Kaseh, 1996).

The alternative way to improve feed efficiency is through the improvement of environmental factors such as nutrition. Improvement of the nutritional value of food through improvement in nutrient utilisation will reduce the cost of the production process. Many attempts had been made to improve the nutritional value of food by pelletting, addition of enzymes, soaking the grains and heat treatment (El-Kaseh, 1996).

With respect to improving efficiency in broiler chicks, one solution is to increase the fat percentage in the starter diet. The current fat percentage levels in broiler diets are based on studies conducted in the 1960s and 1970s (Larbier and Leclercq, 1992). However, since then with intensive breeding, modern broiler hybrids have significantly become leaner and faster growing. Their fat requirements might have altered accordingly, as did the utilization of stored yolk fats in the gut of broiler chicks during the first few days after hatching (Appleby *et al.*, 2004).

The objective of this thesis is to study the effect of high fat levels in broiler diets, particularly in starter diets on feed selection, behaviour and growth performance under a variety of conditions.

Aside from the relevance to poultry producers, there is a broad dimension to the thesis. Although world food production more than doubled in the 20th century (Avery, 1995; Lomborg, 2001), there remain many starving people. Given that the world's population is likely to reach 8–9 billion by 2050 (Avery; and see Lomborg, 2001), the world needs a further dramatic increase in food production. Meat production is especially important in this regard. This is because (a) it is difficult to live a healthy life without eating meat (Harris, 1986; and see Avery 1995), and (b), as people become richer, they eat more meat (Avery, 1995; Harris, 1986). Re the latter point, the world is increasingly becoming richer; even sub-Saharan Africa is richer now than it was 50 years ago, and absolute numbers of people suffering famine are falling. One can conclude there will be a huge increase in demand for poultry, and this implies a need for more efficient poultry production.

There is a related issue. The world not only needs more food, it needs healthier food. At present in the U.S.A., about 25% of children are obese (Worldwide Obesity Trends, 2007), and throughout the world obesity rates are rising. In the U.K., 27.5% of 16–18 year-olds are obese, and 13% of 8 year-olds are obese (UK Obesity Statistics, 2007). Poultry, especially if it is skinned and cooked without oil, contains little fat, and is, however cooked, healthy (Food Standards Agency, undated).

Finally, the country of origin of the author of the present study is Libya. In Libya, poultry is part of the national cuisine (Libya, incidentally, has a low level of obesity: only 6.2% of her 13–15 year-olds are overweight—Global School-based Student Health Survey, 2007). Libya is at present attempting to diversify her economy, and to improve the living standards of her people (CIA, 2007). Given Libya's recent rapprochement with the West, and the removal of United Nations sanctions against her in 2003, improvement is likely (CIA, 2007). Poultry production in Libya should improve, too.

This thesis comprises 14 chapters, 11 of them reporting experimental work on feeding high fat diets under several conditions.

- Chapter 1: general introduction,
- Chapter 2: literature review,

- Chapter 3: The effect of different fat levels of diets offered in a free-choice feeding regime on feed selection by broiler chicks aged from 1 to 12 days ,

- Chapter 4: The effect of gradual and sudden changes of diet on broiler performance.

- Chapter 5: The effect of free choice feeding on high (8.0%) and low (4.6%) fat diets by male broilers on diet selection preference,

- Chapter 6: The effect of high and low fat diets on the performance of male broiler chickens grown to 30 days,

- Chapter 7: Male broiler chicks feeding preferences with particular respect to birds using colour cues,

- Chapter 8: Effect of wet and dry starter diets given in a free choice selection regime on feeding preference of male broilers from 3 to 7 days –old,

- Chapter 9: The effect of the physical form of diet on feeding preference of male broiler chicks,

- Chapter 10: The effect of supplementation of garlic powder as flavour to the starter crumb diet on the feeding preference of male broiler chicks,

- Chapter 11: The effect of supplemental fat offered separately on the feeding preference of chicks given a free choice selection regime

- Chapter 12: The effect of different levels of fat and protein on broiler chick preferences and performances,
- Chapter 13: Broiler performance and fat content of carcasses,
- Chapter 14: General discussion.

The chapters were arranged according to the order that the experiments were carried out. Many of the experiments were natural extensions from results from previous experiments conducted within this study. The following chapter attempts to provide a succinct summary of previous research in this subject area. A number of the studies reported show clear conflicts or contradictions in terms of results. Attempts are made where possible to explain these conflicts and arrive at a common synthesis of current understanding on the subject.

Chapter 2: Review of the Literature

2.1 Poultry Diet Formulation

Energy is one of the most essential aspects of poultry nutrition. It is necessary for bodily functions and processes such as physiological maintenance, digestion, assimilation, growth, reproduction, and movement. This energy is derived principally from the oxidation metabolism of carbohydrates, fats, and proteins within the food the birds consume. For the majority of poultry diets the principle energy source is carbohydrates, except in certain very high fat-based regimes (Salah *et al.*, 2004a).

While there are several systems for expressing the amount of dietary energy available for assimilation from a feeding regime or specific food ingredient, the most widely adopted standard is Metabolizable Energy (ME). A variety of methods are used to determine ME, including bioassays or estimates based on proximate analysis.

Although fats have the highest potential energy content by weight in the diet (39 MJ/kg compared to 17.5 MJ/kg carbohydrate and 24 MJ/kg protein), there is still some uncertainty as to whether efficiency of utilisation of ME from fat is superior to that from a carbohydrate source, NRC (1975). At the same time not all fats provide the same ME value. Evidence shows that when vegetable fat is substituted in place of carbohydrates (while maintaining constant ME intake) the efficiency of ME utilisation is improved: although not all fats are equally effective (Carew *et al.*, 1964).

Employing high levels of added fat often leads to more ME than can be accounted for from the summation of ingredients. The suggestion is that high fat diets lead to greater retention times of food within the gut, thus resulting in improved digestion and absorption of non-lipid constituents (Mateos and Sell, 1980b; Mateos *et al.*, 1982). In addition, when fat is added as an isoenergetic substitute for carbohydrate there is often an improvement in somatic growth rates, particularly preceding the onset of reproductive maturity. Sell and Owing (1984) noted this phenomenon in turkeys, where adding fat to the birds diet led to increased body weight gain, with the greatest increases in somatic growth rates occurring in birds between 12 and 20 weeks of age. While higher fat levels still improved feed conversion efficiency of birds older than 20 weeks, the increased growth rates become progressively lower as the birds continue to mature (Moran, 1982).

Synthesis of fatty acids occurs principally in the liver, with the rate of synthesis dramatically increasing just prior to sexual maturity. At this time the greatest levels of fat deposition (storage) also occur (Moran, 1985). The costs of synthesis of body fat from dietary fat are lower than from dietary carbohydrate. The provision of fats in the diet has additional benefits. For example, in laying hens, the lipids in egg yolk are formed in the liver, either via *de novo* synthesis of fatty acids or through fatty acids derived from food absorption. Consequently, higher levels of dietary supplied fats during laying, relieve the dependence on fatty acid synthesis and often increase yolk formation and the weight of the egg (March and MacMillan, 1990). This can be of particular advantage in high temperature environments, where added dietary fats can maintain egg production while minimizing heat generation in the effected hens (Valencia *et al.*, 1980).

The general raw constituents of poultry diets are a mixture of foodstuffs: cereal grains, soya meal, fish meal, fats, vitamin and mineral premixes. These ingredients, together with water, provide the essential nutrients (amino acids, carbohydrates, fats, minerals and vitamins) and energy required for a bird's growth, production, reproduction, and maintenance. The commercial diets may also contain additional (non-nutrient) ingredients, including xanthophylls (feed pigments), unidentified "growth factors" claimed to be in some natural ingredients, and antimicrobial agents (which may improve growth and food utilization efficiency) (NRC, 1994).

The starting point for the formulation of poultry diets is usually the energy content of the feed, with the normal selection being an energy level that results in the lowest feed cost per unit of product (e.g., weight gain or eggs produced). Consequently, the feed cost per unit of product is determined by the cost per unit weight of diet and the amount of diet required to produce a unit of product. When high-energy grains and feed grade fats are relatively inexpensive, then high-energy diets are often the most economical. Conversely, if high-energy cereals are expensive, then lower energy diets may be more economical and if a leaner carcass is desired then other levels of dietary energy may need to be considered (NRC, 1994).

Using the concept that poultry tend to eat to meet their energy needs, assuming there are sufficient essential nutrients, then the dietary energy level selected is often used as a basis for setting most ingredient concentrations in the diet (Hill *et al.*, 1956). However, since the physiological mechanisms by which poultry respond to different dietary energy concentrations are not known, although several possible mechanisms have been proposed, caution must be applied when using the above concept (NRC, 1987).

While it is often observed that poultry will adjust their food consumption to achieve a minimum energy intake from different energy level diets, these adjustments are not always precise. In a summary of 34 experiments, Morris (1968) found that laying hens on high-energy diets frequently overconsumed, with the greatest overconsumption associated with characteristically high energy intake strains of birds. At the same time, a large number of broiler chicken experiments have failed to show an inversely proportional relationship between feed intake and dietary energy level, especially for moderate-to high-energy diets (Fisher and Wilson, 1974). This is further supported by more recent studies, which illustrate that growing broilers and turkeys consume more energy when fed high-energy diets compared to those birds fed on low-to moderate-energy diets (Sell *et al.*, 1981; Brue and Latshaw, 1985). For laying hens, variable combinations of carbohydrates, fat, and protein result in more energy intake (Rising *et al.*, 1989). For example, diets with an extra 3 percent fat lead to increased daily feed intake when compared to diets containing no extra fat, while hens fed higher protein diets also consumed greater amounts of energy. In general terms laying hens and broilers are more consistent in regulating their energy intake on low-energy diets (Latshaw *et al.*, 1990), although laying hens are also quite accurate in regulating energy consumption when fed on high-energy diets (Horani and Sell, 1977a).

The general practice for meat-type poultry is to add fat to the diet to increase overall food energy concentration and thus improve productivity and feeding efficiency (NRC, 1994). The oxidation of fats provides an efficient means of cell energy generation, while anabolic metabolism of fats is also required as a part of growth. The majority of lipid deposition occurs in adipose tissue, while additional accrual occurs through cell multiplication, with lipids forming associated membranes. Both forms of lipid assimilation occur simultaneously, although the rates of both mechanisms can vary considerably.

The fat used in poultry feed comes from many different sources, including grease from restaurants, the rendering of animal carcasses, and the refuse from vegetable oil refining. The Association of American Feed Control Officials (1984) defines these source materials, with definitions indicating fat components and limits of non-fat material (Sell, 1988). The moisture (M) content and levels of those compounds that are either insoluble in ether (I) or unsaponifiable (U) often provide no dietary value, and their associated composite (MIU) can be considered foodstuff dilutor. The total fatty acids contributed by all lipid categories, the types of fatty acids present and the proportion of fats in free form provide information in relation to expected digestibility, and how the fats may be subsequently used. The chain lengths of fatty acids, level of saturation, and nature of esterification all have an impact on MIU, which in combination with percentage digestibility influences the ME value. It should be noted that the feed fats present need to be stabilized using an antioxidant to preserve the unsaturated fatty acids, and routinely monitored for the presence of undesirable residues: chlorinated hydrocarbons, unsaponifiables, peroxides, and insolubles (Rouse, 1986).

2.2 Addition of Fat to Poultry Diet

With poultry diets, the terms “fat” and “oil” refer to triglycerides composed of fatty acids. While fat forms the major energy source with the highest caloric value for the birds, only linoleic acid has been defined as an essential nutritional requirement (Baião, 2005). However, dietary fat improves absorption of fat-soluble vitamins such as A, D, E and K, reduces pulverulance, enhances diet palatability, and increases energy utilization efficiency. In addition, fats can increase absorption rates by increasing food retention time in the gastrointestinal tract (Baião, 2005).

The specific energetic value of fats and oils depends upon the number of double bonds, the existence or absence ester bonds, the length of the carbonic chain, the composition of the free fatty acid, the quantity and type of the triglycerides supplement in the diet, the intestinal flora, and the sex and age of birds (Baião, 2005). It is also frequently observed that the body fat composition is dependent on the composition of the fat in the diet. It is notable that in the first days of a bird’s life, the apparent digestibility of saturated fat is low. Not surprisingly, there are a number of methods used to assess the quality and quantity of oils or fats in diets: titration, moisture, impurities, unsaponifiable, saponification value, percentage of fat, percentage of free acids/acidity and the profile of fatty acids. The feed’s nutritive value improves husbandry performance, with composition and quality of the carcass being changeable by using oil or fat in bird diets (Baião and Lara, 2005).

Different fatty acids do not have the same ME because of variability in absorption across the alimentary tract. Thus, Lewis and Payne (1966) defined the value of any particular dietary fat to the chick or hen by considering the efficiency of utilization of the individual constituent fatty acids as either sources of energy or in terms of other metabolic functions. Both Carew and Hill (1964) and Horani and Sell (1977b), among many researchers, have reported that ME of diets with supplemental fats exceed the total sum of MEs of constituent dietary components. Yet because it is thermodynamically impossible for the ME of fat to exceed its gross energy concentration, the supplemental fat must have exerted an energetically favourable effect on either digestibility or energy utilization of other dietary constituents. This improved energy utilization efficiency, through fat supplementation, has also been observed in chicks (Carew and Hill, 1964; Sell and Thompson, 1965). In addition, Touchburn and Naber (1966) also observed a similar dietary fat improved utilization of ME, while also demonstrating that a wider calorie:protein ratio could be tolerated when fat was added to a bird's feed. Jensen *et al.* (1970) obtained a quantitative estimation of this "extra-caloric" effect of added fat. A number of additional studies have demonstrated similar extra-caloric effects and improved non-lipid constituent utilization (Sunde, 1956; Gomez and Polin, 1974; Sibbald and Kramer, 1978; Mateos and Sell 1980a). Jensen *et al.* (1965) reported that, in the absence of supplementary fat, the protein requirement of male turkeys was shown to be higher than that for female turkeys and their subsequent growth rates are lower (Waibel, 1955).

There are at least two mechanisms whereby fat could influence dietary energy utilization (Mateos and Sell, 1980c). The first is increasing food retention time in the gut, thus leading to increased absorption rates (Sturkie, 1976). The second is that the fatty acids of supplementary fat may synergistically interact with other fats inherent in the diet leading to improved micelle formation and energy utilization (Leeson and Summers, 1976). While the weight of evidence suggests fat supplements lead to overall improved physiological performance, Plavnik *et al.* (1997) observed no difference in weight gain, feed efficiency, carcass fat, or muscle percentage as responses to fat or carbohydrate supplementation, either in broiler chickens of different ages or in growing turkey pullets. Rosebrough *et al.* (1999) reported similar zero improvement effects (either in terms of changing body weight, feed intake, or the food utilization efficiency) when replacing dietary carbohydrate calories with fat calories. Other evidence suggests that improvements from fat supplements are often strongly age-dependent (Chamblee *et al.*, 1992).

Nevertheless, Bou *et al.* (2005) observed that the changes in dietary fat composition had a strong effect on the fatty acid compositions of mixed raw dark and white chicken meat with skin. It seems that fish oil diets produce meat with the highest eicosapentanoic acid (EPA) and docosahexanoic acid (DHA) content, whereas linseed oil diets produce the highest concentration of n-3 polyunsaturated fatty acids (PUFA), especially linolenic acid in meat. However, meat from birds fed on animal fat diets is also very rich in long-chain n-3 PUFA compounds. Waldroup and Waldroup (2005) demonstrated that the fatty acid composition of the adipose tissue of the broiler is significantly influenced by the fatty acid composition of the diet.

2.2.1 Factors Affecting the Digestibility of Fats

A number of studies have shown that ability of newly hatched chicks to absorb fat is initially incomplete but improves rapidly with age (Mahagna *et al.*, 1988).

For example, the digestibility of fat one week after hatching is lower for broiler breeder males when compared to birds of 2 or 3 weeks of age (Carew *et al.*, 1972). A further two experiments also demonstrated that apparent digestibility of fat was highest after the third week of life (Zelenka *et al.*, 1987). These results are supported by Noy and Sklan (1995), who reported that the digestion and the absorption of fats in chicks between 1–21 days old was 85% higher at age 4 days than the first three days and continued to increase thereafter. This suggests that effective lipases activity and bile salts production is reached 4 days after hatching (see also Freitas 1999, Cancado, 1999).

Garlich and Nesheim (1965) showed the importance of bile salts by demonstrating that the addition of 0.3% and 0.6% of a bile salt improved the fat absorption in chicks fed unheated soya meal. In addition, they noted that 5% of bile added to a diet containing 20% tallow improved the apparent absorption of the fat from 47% to 69%. Edwards (1962) also noted slightly improved fat absorption efficiencies for chicks fed diets containing cholic acid. Fedde *et al.* (1960) reported that a decrease in the ionized calcium level in the gut results in the formation of insoluble soaps, and consequently young birds can utilize more dietary tallow. Although, digestion of fatty acids showed little change in birds between 4 and 21 days of age, they did find that secretion of lipase in broiler chickens was low at hatching and increased twenty fold between 4 and 21 days of age (Noy and Sklan, 1995). Pancreatic lipase activity may be a limiting factor in lipid digestion in young birds (Krogdahl and Sell, 1989).

The low replacement rate of bile salts in young chicks (Serafin and Nesheim, 1970) appears to account to some extent for lower fat absorption efficiencies of juvenile birds (Renner and Hill, 1960).

Evidently, dietary fats vary not only in terms of composition but also in their metabolic contributions. Wiseman (1984) concluded that the digestibility of fats depends upon numerous factors, including:

- Type of fat;
- Level of saturation;
- Level of fat inclusion in the diet;
- Presence of other dietary components;
- Age of the bird.

Interestingly, Calloway *et al.* (1956) showed that the melting point of a fat is not a reliable index of digestible coefficient, and that the relationship between digestibility and melting point is coincidental rather than causal.

2.2.1.1 Type of fat

Since the 1950s, many of the improvements in weight gain and food utilization efficiency within the poultry industry have come about through the use of high-energy feeds. The fats and oils in feeds are the greatest contributors of energy per unit weight of any feed ingredient. According to Yacowitz (1953), soya oil, cottonseed oil, and lard exert virtually identical effects upon growth and the efficiency of food conversion. Yet other studies have shown there is a definite interaction between fats and fatty acids as energy sources for chicks, since mixing saturated fats with relatively unsaturated fats increases the utilisation of saturated fats. The same interaction is also observed with specific fatty acids. The interaction between fats and fatty acids can make the utilisable energy from saturated animal fats almost equal to that derived from unsaturated oils. It is important to note that vegetable oils, because of their high level of unsaturation, are also subject to higher oxidation rates and higher levels of rancidity compared to animal fats. Consequently, by selective mixing of both animal and vegetable lipids the overall utilisable energy of animal fat can be increased, while at the same time, producing a more stable feed mixture.

Carew *et al.* (1964) observed that metabolic efficiency and energy utilization was affected by the amount and composition of fat in chick diets. De Groote *et al.* (1971) also showed that the metabolic efficiency of ME utilization for maintenance plus growth was higher for fats than for glucose. Kalmbach and Potter (1959) reported differences in MEs for different fat sources when the glucose level of the diet was changed. In addition, Volker and Amich-Galli (1967) suggested that losses of ME occurring during metabolism are lower for animal fats than for vegetable fats. Yet Veen *et al.* (1974) reported that ME values for soya oil and a blended animal fat differed by 1.486 Kcal/g (9.168 ± 120 vs and 7.682 ± 0.108 vs, respectively). In contrast to these reported physiological differences, both Edwards and Hart (1971) and Bartov *et al.* (1974) were unable to show any changes in carcass composition from the isocaloric substitution of fat, for carbohydrate-derived calories.

Carew and Hill (1966) concluded that corn oil increased tissue energy gain per unit of metabolizable energy (ME). Griffiths *et al.* (1977) also subsequently reported that supplements of corn oil and poultry grease produced significant increases in body weight gains of male broiler chicks between 1–4 weeks, although they failed to show any significant effects on carcass composition or abdominal fat pad size for birds on dietary fat levels of 0, 3, 6 and 9 %. Andreotti *et al.* (2004) reported a positive linear effect of soya oil on weight gain, energy intake and feed intake, and quadratic relationships for feed:gain and energy:gain ratios.

While Carew *et al.* (1964) have suggested that animal fats such as beef tallow and bone fat were at least equally effective as the vegetable fats (such as corn, soya, and olive oil) in increasing energy utilization efficiency, the same cannot be said for oils such as coconut. These oils, that contain predominantly short-chain (C12, C14) saturated fatty acids (lauric and myristic acid), are ineffective in increasing energy deposition in chicken carcasses, suggesting they are less efficiently metabolized (Amich-Gali and Ross, 1967).

According to Carew *et al.* (1963) growth stimulation by corn oil and soya oil is independent of changes in metabolizable energy and or concentration in the diets. Rand *et al.* (1958) observed increased growth rate and nitrogen retention in chicks when corn oil replaced dietary carbohydrates. Similar to previous conclusions, Hopkins and Nesheim (1961) believed the growth promoting activity of soya oil was due to specific components of the oil rather than its energy contribution. Further studies by Sibbald *et al.* (1961; 1962) and Lall and Slinger (1973) showed that mixing of tallow with soya oil or rapeseed oil/soapstock produced apparent metabolizable energy (ME) values greater than the sum of the component fats. In addition, March and Biely (1957b) obtained no changes in fasting oxygen consumption when high levels of beef tallow or herring oil were added to chick diets.

Interestingly, the substitution of refined sunflower, soya and corn oil up to 200 g/kg of diet, compared to a diet containing all natural sunflower oil had no adverse effect on the performance of young (12 day old) or older (42 day old) birds (Rodriguez *et al.*, 2005). Meng *et al.* (2004) also observed no affect on body weight gain when using either beef tallow or canola oil. However, a poorer feed: gain ratio was noted for diets containing tallow. At the same time Meng *et al.* (2004) also noted that addition of carbohydrase enzyme improved fat, starch, nitrogen, and non-starch polysaccharide digestibilities in the small intestine. There was also improved apparent ME, and reduced jejunal digesta viscosity for both fat types. An additional study by Bilal *et al.* (2001) reported no effects on broiler performance, abdominal fat accumulation rate, and blood parameters observable under different fat regime diets.

While also observing fatty acid composition of broiler chicken abdominal fat, Balevi and Coskun (2000) observed the lowest food consumption and weight gain in groups fed fish oil, the greatest food consumption in groups fed tallow, and the highest weight gain in groups fed corn oil. Corn oil fed chickens had the lowest food conversion ratio. In terms of n-3 abdominal fat levels the group fed flax oil presented with the highest concentrations, with the groups fed rendering oil showing the lowest; saturated fatty acid levels were highest in birds fed a diet containing tallow.

While Deaton *et al.* (1981) among others have reported that body fat increases with the amount of dietary tallow (composed essentially of saturated fatty acids), there is only limited information available on the comparison of the effects of specific fats on the synthesis of cholesterol in avian species.

For example, Phetteplace and Watkins (1990) reported that as levels of dietary n-3 fatty acids and polyunsaturated:saturated ratios increased, the concentration of triacylglycerols decreased in the plasma and in the very low density plus low-density lipoprotein fractions. Conversely, mature roosters fed fish oil showed no significant decrease in plasma triacylglycerols compared with those fed corn oil (Daggy *et al.* 1978).

It is known that the hypolipogenic effect of n-3 fatty acids (fish oils) is greater than that of n-6, which is, in turn, greater than that of saturated fatty acids (animal fats). For example, in male Japanese quail, Hood (1999) observed that body pools of both cholesterol and fatty acids were lower in birds fed tuna oil than in those fed a diet containing beef drippings. Hood (1990) also studied the effects of dietary safflower oil, tuna oil, linseed oil, and beef drippings on blood lipid profiles and on hepatic synthesis of cholesterol in male Japanese quail. Hood found the lowest blood cholesterol levels in birds fed tuna oil while the highest levels were found in birds fed beef fat (birds on safflower and linseed oil diets showed intermediary effects). The same patterns were observed for rates of hepatic cholesterol synthesis. Once more it appears that triglyceride concentrations are lower in birds fed n-3 fatty acids compared to either animal or plant lipids.

An additional study of body fat composition by Hrdinka *et al.* (1996) observed similar fatty acid patterns in abdominal and subcutaneous fat that differed significantly from fat extracted from the breasts and thighs. However, the specific patterns of fatty acid composition were significantly affected by the dietary fat sources: differences were most pronounced for adipose tissues, with these tissues containing more polyunsaturated and fewer saturated fatty acids compared to breast and thigh tissues.

Gonzalez-Esquerra and Leeson (2000) showed significant n-3 meat enrichment in birds fed flaxseed and menhaden oil for just 7 days prior to slaughter. The study also recorded preferential deposition of linolenic acid in dark meat and of the long-chain n-3 fatty acids in white meat. A further study by Kahraman *et al.* (2004) reported a desired fatty acid composition of tissues for birds fed a diet containing an oil source. But, using fish and vegetable oils rich in long-chain unsaturated fatty acids in broiler diets can potentially increase fatty acid oxidation in muscle tissues. Kralik *et al.* (2003) showed that a supplement of rape seed oil and rape seed to broiler diets lowers the content of saturated fatty acids (SFA), but increases the content of monounsaturated fatty acids (MUFA) and alpha-linolenic fatty acid in muscles and in abdominal fat. Ortiz *et al.* (2006) also concluded that seeds of high-oleic acid content and conventional varieties of sunflower could be used in poultry feeding regimes in order to increase both monounsaturated and polyunsaturated fatty acid contents in both abdominal adipose tissue and intramuscular fat.

Sanz *et al.*'s (1999) study also supports the conclusion that dietary fat composition determines fat consistency of meat, with fat sources rich in linoleic acid producing marked differences in meat fat composition with only a moderately higher susceptibility to lipid oxidation. An earlier study, by Scaife *et al.* (1994), concluded that food intake and live weight are highest in birds fed on diets containing beef tallow and lowest for birds fed diets containing rapeseed oil. Related to this, Golian and Maurice (1992) showed that the addition of poultry grease to a corn and soya meal based diet can increase the total lipid digestibility of the diet for broilers.

Under stressful semi-arid climatic conditions, Ozdogan *et al.* (2004) suggested that vegetable oils rather than tallow improved fattening performance of broilers. Azman *et al.* (2005) also concluded that soya oil supplements produce better carcass quality through increasing polyunsaturated fatty acids (mainly linoleic acid) in the skin, abdominal fat, and breast muscle of the birds. Also, the study showed that the food conversion ratio, daily weight gain and daily feed intake of birds fed on poultry grease was superior to groups fed on beef tallow, although their were no detrimental effects on growth performance for birds fed on tallow.

Analysis of egg yolks has shown increased saturated fatty acid and decreased polyunsaturated fatty acid levels in young and old hens fed on prilled fat (Grimes *et al.*, 1996), with birds also showing increased gastrointestinal food transit times (increasing from 29 to 31 min) when compared to groups fed dietary poultry fat. However, Ouyang *et al.* (2004) observed no significant effect of different oil sources in feed on the weights of eggs, egg white, or body weight, nor on C16 , C18:3 n-6 or C20:4 n-6 contents in the yolk.

Interestingly, Korver and Klasing (1997) demonstrated diets supplemented with fish oil could play a role in modulating the responsiveness to immune challenges, resulting in improvement of performance characteristics of broilers. Similarly, Azman and Seven (2005) observed that dietary fat sources affected nutrient and mineral retention. For example, soya oil supplementation resulted in significantly higher retention of dry matter, crude protein, ether extract, crude fibre, ash, organic matter, and N-free extract, while poultry grease supplementation increased the Ca retention; beef tallow supplementation caused the lowest Ca retention, and chicks fed with soya oil diet had the highest P retention.

2.2.1.2 Saturated and unsaturated fatty acids

It appears that both stearic and palmitic acids are virtually unutilized by the chick when fed singly in the diet (Renner and Hill, 1961a); but when the saturated fatty acids were fed in a mixture containing fats such as hydrolyzed lard or beef tallow there was a significant improvement in the absorbability of both acids, particularly palmitic acid (Renner and Hill, 1961b). It also appears that oleic acid plays a direct role in facilitating the absorption of saturated fatty acids (Young and Garrett, 1963).

The degree of fat saturation is known to be important for fat utilization by chicks (March and Biely, 1957a). The maximum absorption value for the monoglycerides in a homologous series of saturated monoglycerides was achieved with fatty acids containing 12 and 14 carbons, with decreasing absorption for longer chains. Conversely, the absorption of palmitic acid by birds fed various monoglycerides progressively increased to a maximum in mixtures containing monomyristin. The absorption subsequently decreased when fed mixtures containing monopalmitin or monostearin (Garrett and Young, 1964, 1975). Renner and Hill (1961b) also demonstrated the importance of chain length; they additionally showed that the absorbability of mixtures of fatty acids by chicks is influenced by the presence or absence of an ester linkage to a glyceride moiety, and that the absorption of fatty acids is dependent upon the point of attachment to triglyceride molecules. In fact, Mattson and Streck (1974) demonstrated that the absorption of a saturated fatty acid was increased if the molecule was located at position 2 of the triglyceride molecule. Conversely, free fatty acid (FFA) is poorly absorbed in chicks when compared with triglycerides or a mixture of glycerol and FFA (Sklan 1979).

Wiseman and Salvador (1990) studied three fats and their corresponding acid oils: tallow and tallow acid oil; palm and palm acid oil; soya and soya oil. The above were all fed to broilers to determine the influence of free fatty acid (FFA) content and degree of saturation on the apparent Metabolizable Energy value. They found the degree of saturation had a pronounced effect upon the apparent metabolizable energy of fats and that the values decreased in the following order: soya oil, tallow, and palm oil.

Earlier, Young (1961) had observed that the absorption of certain saturated fatty acids is influenced by the amounts of unsaturated fatty acids in the diet. They reported that palmitic and stearic acids were utilized poorly by chicks when fed alone, but absorbed significantly rapidly when fed in a mixture. In a later study Garrett and Young (1964) demonstrated that the absorption of oleic acid was greatly enhanced by the presence of sufficient quantities of bile, while oleic acid also improved the absorption of palmitic acid. Garrett and Young (1975) proposed that the extra-caloric effect of supplemental fats might be due to a positive interaction between unsaturated fatty acids present in dietary ingredients and the saturated fatty acids supplied by the additional fats. Leeson and Summers (1976) came to a similar conclusion: a synergism between saturated fatty acids of a supplemental fat of animal origin and unsaturated fatty acid inherent in other ingredients of a diet may enhance the ME of supplemental fats. Kalmbach and Potter (1959) and Cullen *et al.* (1962) observed that the ME of either saturated or unsaturated fats varied depending upon whether semi-purified or practical diets were used.

When the carcasses of cockerels fed on the Wesson oil-cholesterol diet were analysed the percentages of the saturated acids (palmitic, stearic, and arachidonic) were significantly decreased, while linolenic and linoleic acid levels increased: oleic acid levels remaining the same (Klopfenstein and Clegg, 1977). There are also differences in fat composition depending upon post-slaughter meat treatment. Cortinas *et al.* (2004) observed that a reduction in total fatty acid content in cooked thigh meat affected monounsaturated fatty acids, saturated fatty acids and polyunsaturated fatty acids in similar proportions. Furthermore, they observed that dietary polyunsaturation and alpha-tocopherylacetate (alpha-TA) supplementation affected lipid oxidation more markedly in cooked meat and cooked refrigerated meat than in raw meat and raw refrigerated meat. Lipid oxidation in cooked meat showed a significant linear increase as the concentration of polyunsaturated fatty acids in raw meat increased (Cortinas *et al.*, 2005).

Korver *et al.* (1998) demonstrated that increasing the energy content of broiler diets with oils high in polyunsaturated fatty acids improved broiler performance, while increasing the energy content using tallow (high in SFA) led to no significant improvements. Crespo and Esteve-Garcia (2001) study concluded that polyunsaturated fatty acids produce lower abdominal fat deposition than saturated or monounsaturated fatty acids. A later study by Crespo and Esteve-Garcia (2002a) demonstrated that broilers fed saturated fat tend to deposit more fat in abdominal and mesenteric depots. The same study showed that broilers fed linseed oil had less abdominal fat than broilers on tallow diets (Crespo and Esteve-Garcia, 2002b). From their earlier findings, Crespo and Esteve-Garcia (2002c) suggested that lower abdominal and body fat deposition of broilers fed polyunsaturated fatty acids was mainly due to differences in lipid oxidation rates compared with metabolic rates of birds on saturated or monounsaturated fatty acid diets. The observed higher *in vivo* lipogenesis found in broilers fed linseed oil would be a further mechanism by which energy could be dissipated, and thus contributing to a reduction in fat deposition in these birds. A study by Newman *et al.* (2002) likewise showed the development of leaner birds fed on n-3 and n-6 polyunsaturated fatty acids, but it also noted higher food conversion efficiencies in the birds. Newman *et al.* (2005) suggested that the type of dietary fats in the feed could modify glucose metabolism of birds, with the result that the changes to glucose utilisation affected the energy metabolism of broilers.

A study by Villaverde *et al.* (2004) examined the relationship between different levels of polyunsaturated fatty acid (15, 34, 45 and 61 g /kg) and vitamin E (0, 100, 200 and 400 mg/kg) in broiler diets. The evidence suggested that the levels of polyunsaturated fatty acid were not a limiting factor in terms of vitamin E absorption: although polyunsaturated fats may increase vitamin E degradation in the gut. Once more the same study reported that polyunsaturated fatty acid rich diets result in lower body fat deposition compared to saturated fat rich diets. Yet increasing both the fat levels and the proportions of polyunsaturated fatty acids in the diet of birds led to no changes in body fat when compared to lower fat diets containing proportionally less polyunsaturated fatty acids (Villaverde *et al.*, 2005).

Utilizing the observed effects of polyunsaturated dietary supplements, Sanz *et al.* (2000a, 2000b) suggested that the use of an unsaturated fat source during the first stages of growth, and a subsequent switch to a saturated fat supplement for a few days before slaughter, may offer the advantage of lower abdominal fat deposition while also providing an acceptable fat fluidity. This approach would provide the performance enhancements suggested by Zollitsch *et al.* (1997) in comparison with the practice of using saturated fat as the sole dietary source during the whole growing and finishing period. A later report by Sanz *et al.* (2000c) once more identified that broilers fed sunflower oil-enriched diets had a lower fat deposition in comparison with broilers fed tallow-enriched diets.

In a species comparison study, Mossab *et al.* (2000) stated that at 1 week of age, turkeys utilized fats, especially saturated forms, more efficiently than young chickens (i.e. total fatty acid digestibility was 96.5 vs. 86.4 % for soya oil and 75.0 vs. 49.1 % for tallow). The difference between the two species disappeared at 3 weeks of age, with chickens increasing their fat utilization (95.7% vs. 99.3% for soya oil and 64.0% vs. 69.7% for tallow) and turkeys maintaining their initial utilization rates (96.5% vs. 99.3% for soya oil and 75% vs. 69.3% for tallow).

2.2.1.3 Levels of fat in the diet

An early study by Biely and March (1957) suggested that the relationship between dietary fat level and dietary ME content was a positive linear function. This increasing ME was at least partly explained by Allison's (1958) report that protein utilization increased with increasing levels of dietary fat or metabolizable energy. The apparent absorption coefficients of fats by chicks were similar for either 10% or 20% dietary fat levels and were high for safflower oil, corn oil and hog grease, and low for beef tallow (Fedde *et al.*, 1960).

A later study by Carew *et al.* (1964) reported that 35% of corn oil in the diet was nearly as effective in improving energy utilization efficiency as levels of nearly 10% corn oil. In terms of fat deposition, Martin and Woodroof (1966) reported that including 5 % coconut oil, beef tallow, sunflower oil and menhaden oil in the diet, all modified carcass fat composition, with appreciable quantities of most of the major fatty acids in each dietary fat being deposited in the carcass. This suggests that fats interacted with other dietary components. DalBorgo *et al.* (1967), using different fat levels, reported that the main carbohydrate constituent of the test diet modified the degree of utilization of energy from raw soybeans. Later, Essary *et al.* (1968) found that diets with 8% added fat significantly increased the skin percentage in market turkeys. Jackson *et al.* (1969) reported that diets with up to 28.25% added tallow at constant calorie:protein ratios (feed conversion measured as kg feed required per dozen eggs) decreased energy utilization efficiency of birds as dietary fat levels increased. However, they also reported that daily ME consumption was increased from 1.1 to 1.5 MJ with the feeding of tallow. In contrast to these findings Daghin (1973) reported improved food conversion rates and reduced feed intake with higher-energy diets. Around the same time, Kubena *et al.* (1974) noted that an increase in abdominal fat as dietary energy levels increased. Further support for this general pattern was provided by Velu and Baker (1974), who reported that intake of feed decreased and gain per unit of feed increased linearly as dietary corn oil levels increased. The average egg weight was increased from 58.6 to 60.7g with the feeding of 15% supplemental fat (Reid and Weber, 1975).

Fuller and Rendon (1977) studied the effect of dietary fats corn oil, palm oil, acidulated cotton seed soapstock (ACSS), coconut oil, tallow, poultry fat, and feed grade animal fat on growth of young chicks at a single dietary fat supplement of 11.6%. In another trial, all fats except ACSS and coconut oil were tested at levels of 10 and 20%. The trials showed that heat increment (HI) increased as the diets progressively contained higher proportions of fats. Results showed that calorific efficiency (GE gained / ME consumed) was greater in fat supplemented diets compared with low fat controls, while the general pattern was for higher calorific efficiency with increasing percentage dietary fat content. However, although all the fats except ACSS and coconut oil improved the weight gains of the chicks in one trial, they failed to do so in others. Nevertheless, Horani and Sell (1977a) continued to report that the addition of 2 or 4% fat to laying hen rations (based on corn, oats, barley or combinations of these grains) significantly decreased feed consumption and improved feed efficiency.

Following on from these previous trends, Sibbald (1978) found that replacing 10 to 20% of tallow with vegetable oils was sufficient to increase fat AME to levels greater than biochemically predicted; these results were also supported by the observations of Ketels and DeGroote (1988) who found that replacing a 10%

supplement of beef tallow with a 10% supplement of soya oil increases the U: S ratio of the dietary blend from 1.35 to 1.80. Thus the supplement results in an improvement of the apparent ME for the added fat from 25.5 to about 29.3 MJ/Kg, significantly higher than the recommended value of 26.4 MJ/Kg. It is not surprising that Cherry (1979) found that hens given a diet high in metabolizable energy (ME: 12.5 MJ/kg) gained more weight than similar birds on a low ME diet (11.5 MJ/kg) for 112 days.

Mateos and Sell (1980c) further investigated the interactions between dietary fats and carbohydrates by studying the influence of four levels of yellow grease (0, 3, 6 and 9%) and six carbohydrate sources (sucrose, starch, maltose, glucose, fructose and glucose + fructose) on utilization of pure carbohydrate by laying hens. Once more, the extra calorific effect of added fat was seen as they found the ME of each carbohydrate increasing with each increment level in supplemental fat. A later study by Zatari and Sell (1990) found that dietary animal-vegetable fat at a level of 6% increased weight gain and improved feed efficiency at all levels of sunflower meal (0, 10, or 20%) in the diet.

In a study reported a year later, Ajuyah *et al.* (1991) fed eight diets containing two levels (10 and 20%) of either full fat flax seed (FFS) or full fat canola seed (FCS), and two levels (3.5 and 7.0%) of canola oil (CO) in combination with either flax meal (FM) or canola meal (CM) at 6.5 or 13% to broiler chickens. As in a few of the previous studies, they found that the 20% diet produced significantly lower live weight and smaller carcass, breast, leg and neck weights. Feeding 20% FFS, 20% CO and ME, and 10% FCS all depressed breast yield. Further analysis showed that tissue cholesterol and lipid contents were lower in white and dark meat for all the experimental diets. Birds fed flax products contained less fat in white and dark meat than the birds fed Canola. Addition of either FFS or 13% FM to the diet resulted in significantly reduced carcass fat.

At lower concentrations of added fats, Barker and Sell (1994) reported that chicks fed diets containing 5% animal-vegetable fat for up to 45 days progressively improved their feeding efficiency and gained more weight compared to chicks on diets containing 1% animal-vegetable fat. Peebles *et al.* (2000) looked at relatively low concentrations of poultry grease compared with corn oil and lard at 0, 1.5, and 3% of the diet and the added dietary fats did not appear to effect production, egg weight, or hatchability. However, Peebles *et al.*'s (2000) study showed that body weight increased, as generally observed, when fat was added to poultry diets.

Lopez-Ferrer *et al.* (1999) reported that replacing fish oil with vegetable oil (linseed oil and rapeseed oil) improved the sensory quality of meat. In a supplementary paper, Lopez-Ferrer *et al.* (2001a) reported the performance, fatty acid composition, quality, and sensory traits of broilers were affected by a diet containing additional fish oil. They provided birds with three different fat-supplemented diets: 1) 4% fish oil + 4% tallow for 4 weeks, followed by 1% fish oil + 3% linseed oil + 4% tallow for 1 week; 2) 4% fish oil + 4% tallow for 3 weeks followed by 1% fish oil + 3% linseed oil + 4% tallow for 2 weeks; and 3) a control diet containing 8% tallow.

They again reported that sensory quality of the meat from birds given the first two diets did not have a fishy taint when compared to controls. In a further experiment, they studied the effect of linseed oil on additional meat quality parameters and found no significant differences among treatments in meat quality (Lopez-Ferrer *et al.* 2001b).

In more recent studies, Rodehutscord *et al.* (2002) showed a positive effect of carnitine supplementation on feed conversion at high dietary fat levels (8 %) rather that lower fat levels (4%). Ozpinar *et al.* (2003) reported that the monounsaturated fatty acid level of meat samples of broilers fed diets containing fish oil was significantly higher than that of diets containing 4% fish oil + 2% linseed oil; 2% fish oil + 2% linseed oil + 2% sunflower oil; and 6% soya oil. Laffitte *et al.* (2003) found that fat digestibility of the blends of fatty acid distillates (FAD) at an inclusion of 6% was 9.9% lower than when 6% soya oil was substituted. Higher hepatic cholesterol accumulation was reported by Feoli *et al.* (2003) for birds fed 15% coconut fat and 1% cholesterol compared to birds fed 15% soya oil and 1% cholesterol.

In a subsequent fat accumulation study Bou *et al.* (2004) stated that diets containg 2.5% fish oil produced meat with an eicosapentaenoic and docosahexaenoic acid content double that of diets containing 1.25% fish oil. At relatively low fat concentration levels (3%) Mazalli *et al.* (2004a) indicated no influence of different fat source treatments on feed intake, egg production, egg mass, egg weight, feed conversion, yolk colour, Haugh units, yolk index, yolk and albumen percentages, or eggshell thickness. Although they did report that cholesterol content was slightly reduced by the inclusion of greater quantities of unsaturated fatty acids in the diet (Mazalli *et al.* 2004b).

Finally, Tabeidian *et al.* (2005) and Sadeghi and Tabiedian, (2005) observed no effects on carcass, abdominal fat, and liver weight in birds fed different levels of soya oil and protein. In terms of egg production, Cachaldora *et al.* (2006) observed that an increase in the level of inclusion of marine fish oil from 15 to 60 g/kg resulted in a linear increase in concentrations of C20:5 n-3, C22:5 n-3, C22:6 n-3 and total n-3 fatty acid in yolk fat: however, the bird's deposition efficiencies were greatly impaired.

2.2.1.4 Passage of food through the digestive tract

Duke (1989) reported that diet is the most important factor affecting gastrointestinal transit time (GTT). The assumptions are that food contains specific cathartics or that the qualitative and quantitative differences in carbohydrates, proteins, fats, and additives in the food alter transit time. Different carbohydrates have a distinct effect on GTT in chickens. For example, diets containing sucrose and lactose pass through the tract faster than diets containing either glucose or starch (Mateos and Sell 1981).

With respect to supplemental fats the effect on GTT in chickens is largely consistent. Mateos *et al.* (1982) showed that yellow grease included at 0 to 30% in the diet increases GTT in white Leghorn hens during egg production. They further suggested that, as the percentage of supplemental fat increased, the GTT increased. In contrast Golian and Maurice (1992) concluded that GTT (measured with chromic oxide or ferric oxide) was not affected by supplemental fat (at 0, 5, 10 and 20%); this counter proposal is supported by a few additional studies (Tuckey *et al.*, 1958: Golian and Polin, 1984). The slowing in the rate of food passage induced by fat supplementation (yellow grease) in laying hens fed sucrose-based diets does result in more complete digestion according to Mateos and Sell (1980a) as well as enhanced energy utilization (Mateos and Sell, 1980b).

These observations have been extended to all classes of poultry and proposed as an explanation for the extra caloric effect of fat in poultry diets (Summers, 1984).

It appears that age has an effect on the GTT of feed (Shires *et al.*, 1987; Vergara *et al.*, 1989). In general there is an improvement in fat digestion with age (Golian and Maurice 1992). There are indications that, in chicks and young broiler chickens (as opposed to hens), GTT is not influenced to any great extent by fat in the diet. Therefore, the improved absorption of fats and increased ME of diets detected in chicks (Gomez and Polin 1974; Polin and Hussein 1982) cannot be explained by the effect of fat on GTT. In this instance, for young birds the total lipid digestibility increases as the inclusion of supplemental fat increases.

An alternative proposal is that there is development of the digestive tract with age (Katongole and March, 1980), which promotes enhanced digestion, which in turn alters gut motility and transit time. Interestingly, the complexity of the feed may also be of relevance: a study by Rao and Clandinin (1970) indicated that a higher ME for a given ingredient was obtained when practical diets were used, as compared with purified diets. The authors proposed that the rate of passage of purified diets through the gut was considerably faster than that of practical diets. Consequently, the period of exposure of food to the enzymes of the gastrointestinal tract was longer and the utilization of nutrients and energy was greater from practical rather than semi-purified diets.

The sex of the bird might be a complicating factor. Cherry and Siegel (1978) found that the less efficient laying hens had a significantly higher feed passage rate when compared with males. Against this, Washburn (1991) observed no differences in feed passage rate between males and females of the laying strain.

2.2.1.5 Age of broilers

Although the fact that young birds cannot digest fats as efficiently as older birds has been documented for many years, this fact has rarely been incorporated in formulation matrices. For example, Katongole and March (1980) showed a 20–30% improvement in digestion of tallow for 6-versus 3-week-old broilers and Leghorn hens. Sell *et al.* (1986) similarly demonstrated the ability of young turkeys to metabolize various fat sources increased in terms of energy contribution in birds from 2 to 8 weeks of age. This age-related phenomenon does not seem to be of significance with other nutrients (Fisher and McNab, 1987). The reason adult birds are better able to digest fats, and particularly saturated fats, is not clear. Young birds recycle bile salts less efficiently, and this may be a factor as described previously. Also, there is an indication that the fatty acid binding protein is not produced in adequate quantities by young birds.

It has already been reported that the age of birds plays an important role in GTT. Hurwitz and Bar (1966) stated that the rate of passage of digesta through the small intestine was much slower in laying hens than in 7 and 8 week old chickens. This is supported by an earlier report by Hillerman *et al.* (1953). Golian and Maurice (1992) observed a curvilinear relationship between mean feed passage rate and age of the birds. However, Vergara *et al.* (1989) noted that the rate of food passage increases as the birds initially develop in the first 3 weeks of its life.

Supporting the proposition that younger birds are less efficient at processing fats, Freeman (1976) reported that the digestibility of a fat (the nature of which was, however, unspecified) declined with increasing FFA content, and that this decline was more pronounced in younger broilers. Dukworth *et al.* (1950) observed that the absorption of tallow was less efficient in the two-week old chick than in the four to five week old birds. As previously noted, very young chicks appear to be unable to replenish bile salts lost by excretion as readily as older birds (Serafin and Nesheim 1970), but they do have the ability to utilize a higher proportion of their energy requirement in the form of fat (Rand *et al.*, 1958). The increased absorbability of certain fats by chicks does in general appear to increase with age (Fedde *et al.*, 1960). Furthermore, it was confirmed that the absorption of tallow was lowest in two weeks old chicks, and reached an absorbability level at eight weeks of age characteristic of adult birds. Also, the AME value of Prime Tallow (PT) for roosters was much higher than that for chicks (Lall and Slinger, 1973). These data support the finding that older birds utilize tallow better than younger birds (Whitehead and Fisher 1975), and that the effect of age on ability to digest fats is most pronounced for saturated fats (Whitehead and Fisher, 1975). For example, Katongole and March (1980), reported that the ability of chicks, from one day of age to four weeks, to absorb saturated lipids (e.g., tallow and mutton fat) improved. Noy and Sklan (2002) fed chicks differing levels of macronutrients and examined the effects on performance during the first weekpost-hatch and through marketing. They concluded that feeding diets with a wide range of fat or protein at constant limiting amino acids for 1 week did not result in irreversible growth effects.

Age is also very important in learning food preferences. For example, day-old chicks given one-day experience with food and sand show no evidence of a preference for food when tested on day 2. However, three-day-old chicks given one day of experience with food and sand showed a very marked preference for food when tested on day 4 (Hogan, 1973).

2.2.1.6 Physical state of the diet

The early work on steam pelleting (Allred *et al.*, 1957a) indicated an improvement in weight gain and feed efficiency when mash diets were steam pelleted, and showed that pelleting a high-energy diet gave less of a response in weight gain and feed efficiency than the pelleting of a lower-energy diet. This enhanced performance was still evident when fat was included in the diet. Allred *et al.* (1957a, 1957b) presented evidence to show that in addition to the pelleting response being "physical in nature" (reduced ration density), there was also a "chemical effect" involved. This corroborated earlier work by Lindblad *et al.* (1955), which suggested that increased growth and enhanced feed utilisation of broilers fed pelleted barley diets could not be explained on the basis of feed consumption alone. Arscott *et al.* (1958) observed a marked improvement in performance of steam-pelleted barley and maize diets with 0.3 and 6% fat supplementation. However, Combs *et al.* (1958) reported that pelleting a ration containing 10% fat did not improve chick performance. This was supported by Sell and Thompson (1965), who found that increasing the fat level to 10% of the ration decreased the chicks' response to pelleting, although, in the case of efficiency of energy utilisation, the beneficial influence of pelleting was still apparent. Furthermore, the 10% fat ration as pellets or ground pellets increased weight gain only slightly and failed to increase food consumption or to improve efficiency of food utilisation in comparison with feeding the same ration as a mash.

A later study by Shen *et al.* (1985) examined the influence of supplemental fat (0, 3, 6, or 9%) and steam pelleting on the response of broilers to diets varying in energy density. The authors found that increasing the level of dietary fat resulted in little change in volume of feed intake for either the mash or the crumble diets.

The effect of the physical form of feed on food passage was studied by Jensen *et al.* (1962), who concluded that there was little difference in the rate of food passage in chicks fed mash, pellets and ground pellets. The appearance of chromic oxide in the excreta did suggest that birds fed on pellets may convert food more efficiently because less time is spent feeding and so less energy is expended.

Hamilton and Proudfoot (1994) performed two experiments in which male and female broiler chickens were given starter (1–2 days) and grower (22–42 days) diets of fine mash pelleted (FMP), coarse mash (CM), and coarse mash pelleted (CMP). After 42 days, the body weights were different among the mash diets. The body weight feed conversion and monetary returns were significantly improved when broiler chickens were given pelleted diets rather than mash diets. Particle size of the grain used in mash diets influenced the body weights, but to a lesser extent than pelleting of the diets. In another experiment, broiler chickens were fed wheat and barley diets containing whole, ground and pelleted grain. Bennett *et al.* (2002) compared the effect of grain form (whole, mash, or pelleted) on the predicted live performance of broiler chickens. The results showed that, when the broilers ate mash supplement feeds, their growth slowed in all age brackets, but mortality caused by sudden death syndrome, ascites, and heart failure was lowered. The authors observed that wholewheat reduced skeletal problems and that wholegrain increased gizzard size. Against this, wholegrain and mash supplements were associated with a (possibly short term) loss in growth rate, a reduced feed efficiency, and (possibly) better bird health.

2.2.1.7 Colour of the diet

It appears that visual cues are by far the most important factor affecting feeding in very young chickens. Pecking preference for various seeds is unaffected by beak trimming, which removes the sensory proprioceptors in the tip of the beak (Rogers, 1989). Hughes and Wood-Gush (1971b) concluded that without visual or taste cues birds cannot identify the appropriate diet, and consequently birds rely heavily on vision to make food choices. More specifically, round and solid objects are pecked more frequently than angular and flat objects by newly hatched chicks (Fantz, 1957). Young chicks appear to have a predisposition to peck at small, yellow, orange, or red objects (Dawkins, 1971a, 1971b). Although chickens prefer light-coloured feeds, particularly pink (Hess and Gogel 1954), the preferences for other colours can be induced simply by prior exposure to them.

2.2.1.8 The perceptions of birds

Considerations of colour preferences lead to the question of whether birds, including poultry, perceive in the same manner as humans. It is certain they do not.

Picard *et al.* (2000) observed that, apparently, birds' perceptions of food as "new" or "not food" relies on cues that are barely, if at all, detectable by humans. Picard *et al.*'s view accords with evidence from ethology and psychology: certain animal species may be able to out-perform human beings at specific cognitive skills—there is evidence, for example, that pigeons can mentally rotate mirror images better than can people (Hollard and Delius, 1982). Gould and Grant Gould (1995, 1999) argue that such skills have adaptive advantage: it is important for pigeons to be able to identify food, predators, and so on, from all angles because pigeons live in a three dimensional world; humans, by contrast, live mostly in a two dimensional world. Similarly, there are strong suggestions that birds and other animals perceptual processes may be different from thse of humans (see especially Fagot, 2001); pigeons, for example, although they can recognize pictures (indeed, they can distinguish paintings by Picasso from paintings by Monet—Watanabe, 2001), seem less able than humans (or unable) to appreciate occlusion in 2D-representations of 3D-objects (Delius *et al.*, 2001). The consequence of such considerations is that, what may "look" like a pile of indistinguishable grains to a human may contain a variety of grains to a chicken.

Picard *et al.*'s (2000) proposal is made still more plausible by consideration of animals' sensory anatomy and physiology. Many animals have different sensory systems from humans. Bats, as is well known, employ sonar: bats "see with their ears". Many species of bird, including—possibly—all migratory birds, sense the earth's magnetic field to aid navigation (e.g., Wiltscho and Wiltscho, 1996). Most important, as regards poultry, birds have a different ocular physiology from that of humans: birds have four types of cone within their eyes, humans only three. Birds' fourth type of cone is sensitive to ultraviolet (UV) light (Appleby *et al.*, 2004), which humans cannot see.

It is known that broilers use UV detection in mate selection. Both male and female broilers preferentially choose mates when the mates are bathed in UV light (Jones *et al.*, 2001), for instance. Thus broilers are not only sensitive to UV light; they also prefer it, at least in some contexts.

2.3 Digestion

In order to understand the principles behind poultry nutrition it is important to look at the digestive system of birds, as the birds feed requirements are largely determined by the anatomy and capabilities of the birds' digestive tract. These determine what types of feeds can be ingested and digested into the nutrients required to sustain the body and the form in which these nutrients will be delivered (Turk, 1982).

2.3.1 The Digestive Tract

There have been a number of studies of the anatomy of the avian digestive tract (Calhoun, 1954; Bradley and Graham, 1960; Hodges, 1974; King and Mclelland, 1975; Hill, 1976; Turk, 1982; Austic and Nesheim, 1990). The digestive tracts in avian species are relatively shorter than those of mammals (Browne, 1922). Most of this relative decrease is in the intestinal region and suggests that the bird has less area for digestion and absorption than its mammalian counterparts. This leads to shorter times for retention of food stuffs in the gut and less efficiency in recovering the nutrients from food stuffs.

2.3.1.1 Mouth

The mouth of the birds is characterized by the absence of lips and the teeth, and consist of beak, tongue, salivary glands and pharynx which are employed to seize foodstuffs, slightly moisten them, and pass them on to the oesophagus. Little or no reduction of particle size occurs in the mouth area.

2.3.1.2 Oesophagus

This is relatively long, with glands similar to salivary glands found in the lining. In addition to aiding digestion, the glands secrete lubricating mucus to help the passage of food.

2.3.1.3 Crop

The crop is a pouch formed as a specialised area of the oesophagus. It is primarily a storage organ and little or no digestion occurs there, except for some bacterial fermentation or minor salivary amylase activity. Food is moved out of the crop into the lower oesophagus by small groups of contractions within its wall.

2.3.1.4 Proventriculus

It is known as the true stomach which is a tubular organ containing a much thickened mucosa and circular and longitudinal muscle layers continuous with those of the upper and lower gut. It does not serve as a storage organ. Hydrochloric acid and pepsinogen are secreted by the wall of proventriculus.

2.3.1.5 Gizzard

The gizzard follows the proventriculus in the digestive tract sequence. The gizzard is oval, with large, strong and powerful circular muscle and a rudimentary longitudinal muscle, which make its main function to grind or crush food particles.

The gizzard contains the acids and the enzymes that were secreted in the proventriculus.

2.3.1.6 Small intestine

The small intestine is normally considered to have two distinct parts, the duodenum and the lower small intestine, the latter of which is divided into two indistinct parts, jejunum and ileum. Entering the duodenum adjacent to the bile ducts are two or three pancreatic ducts. The pancreas is the source of many digestive enzymes for the hydrolysis of protein, carbohydrate, and lipid constituents of the diet. Enzymes produced in the intestinal wall complete the digestive process by breaking down small fragments of protein molecules to amino acids and by splitting disaccharides such as sucrose and maltose into simple sugars which can be absorbed.

Therefore, most of the digestion and absorption takes place in the small intestine and most of the breakdown of food into nutrients occurs in the ileum of the intestine under the influence of digestive enzymes secreted by the pancreas and intestinal wall and the bile secreted by the liver.

2.3.1.7 Cecae

At the junction of the lower small intestine and the rectum are two blind pouches given off from either side, called cecae. They are paired tubular structures, folded back over themselves at the midpoint of their length. The cecae have little function in digestion although some digestion of fibre may take place in the cecae by action of micro-organisms.

2.3.1.8 Rectum

The rectum is very short in the fowl in contrast to most mammalian species.

2.3.1.9 Cloaca

The cloaca is a chamber common to the digestive, urinary, and reproductive passages, which opens externally at the vent.

2.4 Behaviours

In poultry, feeding behaviour is a series of non-random events. Over small time scales feeding consists of short meals or feeding bouts, while over longer time periods diurnal patterns appear with feeding occurring unevenly across a 24-hour period. This topic has been extensively reviewed by Savory (1979).

Free choice feeding is both more natural and more precise. Under such a system, birds can accurately select a balance of nutrients that meet their particular physiological requirements. Chickens given unambiguous nutritional choice opportunities tend to be healthier and more productive. By indulging their natural appetites, poultry will develop normal digestive tracts and develop a degree of natural resistance to coccidiosis. In addition, changing nutritional needs with natural developmental processes can also be easily accommodated.

However, acknowledging these general statements does mask a number of specific behavioural phenomena. For example, laying birds seem less able to choose wisely than broilers, and they also appear less able to select specific individual amino acids (Forbes and Shariatmadari, 1994). In most of the experiments reported (Forbes and Shariatmadari, 1994; Gous and Swatson, 2000) there is considerable variation in diet selection between individuals that might simply be a reflection of different requirements of protein and energy. However, there is little evidence on which to base such a supposition and further work is required to explain this variation. Perhaps the use of operant conditioning or other methods of quantifying the strength of birds' choices will yield better understanding in this area.

Focusing on other specific behavioural phenomenon, it has been found that young chicks, which are often kept on very long photoperiods such as 23 h light : 1 h dark, show little or no photoperiodicity in feeding early in life, even though they hatch with an inherent circadian rhythm of about 25–25.5 h (Aschoff and Meyer-Lohmann, 1954). Later a gradual diurnal rhythm in feeding develops, especially if chicks are moved to shorter photoperiods. Typically, birds will not feed during the dark period but will do so if the photoperiod is very short, for instance 6 h or less (Morris, 1967).

A further modifier of feeding behaviour in adults and throughout development is social interaction. Even in individual cages, domestic hens tend to feed as group, probably because the sight or sound of one bird feeding triggers feeding in others (Hughes, 1971).

Forbes (1995) reported work by Kempster and Rugg which suggested that hens given a choice between foods could balance their own diets and produce more eggs than those fed a single food. It was confirmed as early as the 1930s that birds can select a balanced diet from among several imbalanced foods (Funk and Graham, reviewed by Forbes, 1995). This phenomenon means that free-choice feeding has received continuous scrutiny since. Laying hens, pullets, growing broilers and growing turkeys all demonstrate an ability to select an adequate diet when offered a choice of two or more foods that alone are inadequate (Forbes and Shariatmadari, 1994). Whether two or more types of food types are presented simultaneously or sequentially birds will self-adjust nutrient intake to meet specific individual requirements. This technique is also useful for determining feeding preferences or specific appetites (Fuller, 2004).

In terms of quantity of food that must be presented to poultry under different husbandry systems, the amount depends upon three main factors: wastage (which is determined primarily by food trough design); energy requirements (which are influenced by ambient temperature, production rate, activity of the birds, feather covering and body weight); and nutrient density of the diet provided (Appleby *et al.*, 2004). Not surprisingly, food intake varies between housing systems, being lower in cages than in non-cage systems. In respect of commercial management, the level of illumination also influences food consumption, with hens showing a preference for feeding in bright (200Lux) as opposed to dim (<1 Lux) light. In two experiments, Newberry *et al.* (1988)

examined the influence of two light intensity treatments, 180 and 6 lx, on behaviour and performance of broiler chickens. They found that standing, walking, and total activity were higher under the 180 lx than the 6-lx treatment, whereas feeding and drinking were not significantly affected by light intensity.

While studying food availability, Preston (1987) noted that birds given restricted access to food spent more time sitting and cage pecking while unable to feed than those feeding *ad libitum* during the same period; they engaged in less agonistic pecking, and the lengths of bouts of drinking during the period of food denial were low compared with the *ad libitum* treatment. After the food troughs were uncovered, birds on the restricted access treatment showed fewer bouts of feather pecking but more bouts of drinking than the birds on the *ad libitum* treatment. He concluded that restricted access to food on a time basis had both positive and negative effects on the welfare of caged layers.

Both feeding regimes and lighting conditions often interact to modify behaviour in animals. However, this appears not to be the case in chickens. Fayed *et al.* (1994) studied 150 chicks evenly allocated to one of 3 treatment groups. The control group were given *ad-libitum* feed and continuous light; the second group was given *ad libitum* feed and daylight; a third group was given continuous lighting and intermittent feeding. It was observed that there was a significant increase in food searching behaviour in birds that were offered food intermittently, but light regime had no effect on these patterns. Interestingly, the body weights of all birds were the same at the end of the experiment, even given the fact that the second and third group were fed less food. Improved food conversion efficiency in intermittently fed birds was seen in comparison to those in the control group. In addition, resting and ground scratch behaviour was significantly higher in the third group than in the other two groups.

The effects of food scarcity was also studied by Murphy and Preston (1988) who observed that birds which experienced less food in pans tended to visits the pans for longer periods, occupied their feeding space more completely, evicted each other more often from pans and were more competitive and less relaxed. The authors also emphasised how environmental factors, particularly food management, could influence bird behaviour when they studied the effect of food depth in pans on the feeding and drinking behaviour of commercially grown broiler chickens aged between 17 and 43 days.

By measuring meal and interval lengths in the eating behaviour of male broiler and layer chickens, Bokkers and Koene (2003) explained that the satiety mechanism for eating can be expressed as the positive correlation between meal length and the length of the preceding (preprandial) interval. At the same time the hunger mechanism for eating was a function of meal length and the length of the succeeding interval. They suggested that, in terms of regulating eating behaviour, the satiety mechanism dominates over the hunger mechanism in broilers, while both satiety and hunger mechanisms are equally involved in layer chickens. More specifically, the typical eating behaviour of broilers and the calculated preprandial and post-prandial correlations indicated that hunger and satiety mechanisms in broilers were very different. In broilers, there was no apparent lower set point, only an upper set point that controlled behaviour, thus suggesting that broilers demonstrate maximal feeding rules.

Nir *et al.* (1994) suggested that behaviour is modified by the form of the food. The authors demonstrated that chicks fed pelleted diets were less active as they sat more and spent less time eating than their mash-fed counterparts. In a further chick study by Paxton *et al.* (1997), the pecking behaviours in 26- to 33-day old chicks, with the exception of drinking, were generally negatively correlated with feeding behaviour, so any non-food pecking by a chick was generally associated with fewer pecks targeted at food. They also reported that chicks aged two months pecked at food on the floor to a far greater extent than at any food presented in food trays. Martaresche *et al.* (2000) suggested that pecking behaviour composed two distinct sets of acts: first, consistently organized patterns that are little affected by the form of the pecked particles; second, non-synchronized acts involved in sensory information.

De Jong *et al.* (2003) found curvilinear relationships between sitting and standing in the home pen, walking in the open field, and level of feed restriction (90%, 70%, 50%, 35% and 25% *ad libitum*). Bokkers and Koene (2004) indicated that motivation is the dominant determining factor for walking in birds with a low body weight, while physical ability is the dominant determining factor for walking in birds with a high body weight.

Savory and Mann (1997) studied the effect of chronic food restriction on growing parent stock (breeders) of broilers. They noted increased pacing before a single daily meal and increased drinking and pecking at non-food objects (oral stereotypies) afterwards. Expression of these activities was correlated positively with the level of restriction imposed, and is thought to be controlled mainly by central dopaminergic mechanisms. In a similar study Sandilands *et al.* (2005)

reported that all feeding behaviours differed significantly between restricted and *ad libitum* fed laying hens during rearing; however, these differences disappeared when the hens matured and all birds were fed the same food regime. More specifically, during rearing periods, *ad libitum* fed birds spent up to 50 % of the time object pecking, whereas this behaviour was virtually non-existent in birds on restricted feeding regimes. Compensatory mechanisms were also supported by Bouvarel *et al.* (2004), who confirmed that feeding high and low protein feeds to broiler chickens from 15 days to market weight on alternate days resulted in performance similar to that from feeding a complete feed, despite large day-to-day variations in lysine intake.

An additional study by De Jong *et al.* (2002) found that feeding restricted broiler breeders had higher plasma corticosterone concentrations at 42 and 63 days of age and a higher corticosterone response to 5 min manual restraint than unrestricted birds. They also found that restricted birds displayed a clear day-night rhythm in body temperature, heart rate, and activity whereas such rhythms were depressed in *ad libitum* fed birds.

Other benefits to restricted feeding regimes have been proposed by Su *et al.* (1999), who concluded that restricted feeding regimes affect the prevalence of leg weakness that was largely independent of changes in body weight. The conclusion was that early developmental feeding restriction reduced many aspects of leg weakness. Meal feeding times and early feeding restriction also improved feeding efficiency.

When Vilarino *et al.* (1996) fed semi-heavy hens two laying diets; one a control, and the other a low-energy diet diluted with 450 g/kg wheat bran, in three different forms: mash, small pellets and large pellets, physical feed characteristic effects were exposed. The experiment demonstrated that the feeding behaviour of laying hens changed dependent on the physical characteristics of the diet, and that this response altered the birds' productivities.

The physiological implications of feed restrictions were also studied by Palo *et al.* (1995) by examining the effects of early nutrient restriction on performance and development of the gastrointestinal tract of broiler chickens. It was found that weights of proventriculus, gizzard, small intestine, liver, and pancreas were affected to only a marginal degree by feed restriction and these organs responded more quickly to refeeding when compared to the whole body.

Not surprisingly, stocking density also influences behaviour of poultry. Andrews *et al.* (1997) concluded that a high stocking density reduced activity in broiler chickens, and that birds stocked at a high density early in the rearing period were most active in the presence of people and showed the longest tonic immobility in response to fearful stimulus. At the same time Oden *et al.* (2002) observed that aggression and feather pecks occurred mainly on the litter or in the nest areas; the behaviours were independent of hybrid variety, but did increase with age in the tiered system. However, they did find that white hybrids reacted more to both the keeper and to a novel object than did the brown hybrids.

With respect to temperature affects, Savory (1986) reported that birds at 8° C had longer intervals between meals, ate larger meals, ate faster during meals, and digested their food more efficiently than at 20° C. At still higher temperatures birds at 32° C ate less food per day, drank more water, had a higher water/food intake ratio, ate slower within meals, had a slower rate of food passage, and had smaller proventriculi, gizzards and caeca than had birds at 20° C.

2.5 Diet Selection

Numerous factors affect food intake including the physical characteristics of the food, such as particle size, colour, taste and smell, and the birds' familiarity with these. All of these features can be said to describe the food's palatability. Particle sizes of about 2–3 mm seem to be preferred by both chicks and older fowl (Perry *et al.* 1976). A number of studies (e.g., Calet, 1965) suggest that, given a choice, chickens prefer particulate diets such as pellets to mash. At the same time, as previously noted, replacing the carbohydrate calories with fat calories in diets results in broiler chicks selecting high-fat diets over low-fat diets under either high-or low-temperature conditions (Dale and Fuller, 1978).

Although Masic *et al.* (1974) reported that broiler chickens eat almost twice as much as layers of the same age, they spend only half as much time eating and take more meals of shorter duration. One potentially important cause of this may be the palatability of the different proteins in the diet; wheat, for example, is preferred to barley, oats, or rye (Cowan *et al.*, 1978). Furthermore, poultry develop a preference to foods they are accustomed to and major changes in diet can result in problems. Unless dietary changes are designed with similar texture, colour and probably taste characteristics there are often observed reductions in food intake and, therefore, a decrease in growth rate or egg production (Appleby *et al.*, 2004).

Flavour is a key aspect of a bird's food. This was illustrated by Balog and Millar (1989) who studied the effect of five flavoured diets (0.06% saccharin, 6% citric acid, 5% salt, 0.10% quinine, or 0.13% aspartame) on food consumption, weight gain, and feeding efficiency of broiler cockerels. They found significant differences in feed consumption between the control diet and all flavoured diets except aspartame. Also, the results showed that birds offered saccharin, citric acid, salt, and quinine ate significantly less of these diets than of the unflavoured control diet. They found that the birds detected the differences in flavour and consumed the feed in a specific order of preference: aspartame, saccharin, citric acid, salt, quinine.

It appears that dietary self-selection is affected by environmental temperatures. Cowan and Michie (1978) reported on how environmental temperature regimens (16, 21, 26 or 31° C) affected free choice of wholewheat and a higher-protein food containing either 252 or 516 g crude protein on broilers aged between 22 and 57 days. They reported that broilers maintained at 16° C and 21° C consumed food at a significantly higher rates than those kept at 26° C, and that, for each feeding treatment, food intake rate was lower for broilers kept at 31° C. Yet at the high temperatures of 26° C and 31° C the 57 day body weight of broilers was still significantly lower than that of broilers kept at 21° C. The conclusion was that although compensation for high temperatures did affect diet selection the birds failed to utilize the increased food intake to match the growth rates seen in birds kept under more optimal temperatures and given complete diets.

Blake *et al.* (1984) considered this temperature-mediated phenomenon by looking at responses of laying hens. They found that bird groups allowed to self-select diets had significantly reduced egg production, and had reduced egg weight and energy intakes at 21° C. At still higher temperatures (30° C) calcium intake and eggshell strength were higher than control groups. The results showed that dietary self-selection did not enable hens to regulate nutrient intake to reach comparable performance parameters to hens provided a balanced diet: thus they were unable to totally compensate and elevate all detrimental impacts.

In a similar study, Brody *et al.* (1984) observed adult male White Plymouth Rock chickens, from lines selected for high (HW) and low (LW) juvenile body weight. The research specifically examined food intake as a function of three variables: dietary self-selection, glucose solutions in lieu of water, and environmental temperature. They found that more energy was consumed by LW males allowed to select between high-protein and high-energy diets, with glucose solutions provided in lieu of water, than on complete diets. They also found that these regimens had relatively little influence on caloric intake in the HW line. Sinurat and Balnave (1986) also studied free-choice feeding of broilers at high temperatures, and reported that broilers a fed complete diets until 21 days of age (but not 44 days of age), grew faster and with a better efficiency of food utilisation than broilers given a free-choice selection of the cereal and protein components. They also reported that with finisher diets, ME and amino acid: ME ratios vary, when given at high ambient temperatures (25° C to 35° C). Broilers on the free-choice system selected diets had similar amino acid:ME intake ratios, but the ratios were lower than birds fed on complete diets.

In addition, Scott and Balnave (1989) stated that egg mass output of pullets was improved by allowing self-selection feeding at hot (25° C to 35° C) temperatures, and at ambient temperatures. Yet it was also observed that there was no beneficial response in egg mass from self-selection feeding at cold (6° C to 16° C) temperatures. Providing 2h of additional light during the dark (cool) part of the day, with or without 2h of darkness in the middle of the extended light (hot) period, failed to produce any effects on egg mass output of pullets at hot (25° C to 35° C) temperatures.

Under conditions of heat stress, with day-time temperatures rising to 33° C, Cumming (1992) demonstrated that broiler chickens will reduce their grain (energy) intake by 34% but their protein intake by only 7%, compared to similar birds in a cooler (20° C) environment. Surprisingly, choice-fed birds have been found to have a "protein memory", which is evidenced by them feeding early the next day, before the temperature rises, and thus obtaining the protein they did not completely consume during the previous day. Thus, in hot environments, the performance of choice-fed broilers is very significantly better than that of the same birds fed more complex and complete diets (Mastika and Cumming 1985).

This phenomenon was supported by work reported by MacLeod and Dabutha (1997), who studied the choice between a high-energy, wheat-based, low protein mixture and a lower-energy, Soya-based, high protein mixture offered to growing Japanese quail at ambient temperatures of 20, 25, 30 and 35° C. It was seen that Japanese quail selected a dietary mixture that maintained protein intake and produced similar growth rates over a wide range of ambient temperature. The protein intake was maintained by altering energy intake in line with thermoregulatory energy demands.

Again under high temperature tropical climate conditions Yo *et al.* (1998) studied self-selection of dietary protein and energy by broilers. They established five groups of birds: T0 received a complete diet (control), T1 a choice feeding system with simultaneous access to an energy-rich feed (ground corn) and a protein concentrate (43.7% CP), and T2, T3, and T4 were introduced to choice feeding after 1, 3, and 5 weeks, respectively, after consuming the complete diet. T1 chicks showed a marked preference for corn, with only 21.4% of their intake being the protein concentrate diet. Intake of the concentrate progressively increased to 40–45% after 3 days of adaptation, resulting in diets with 22.5–24.3% CP. They also found that when broilers fed a complete diet for 1 to 5 weeks (T2, T3, and T4) were changed to choice feeding, the broilers' feed choice intake on the first day was similar to that of T1 chicks at the same age. It was concluded that visual observation and tactile assessment of the feed particles during the initial period allowed the chicks to quickly evaluate the new feeds and to adapt their feeding behaviour.

In respect of specific nutrient selection, Gous and Dupreez (1975) gave layer-strain cockerels, in alternating periods of 6 and 12h, two foods, which were individually poorly balanced but complementary in their amino acid composition. There were no significant differences in food intake or weight gain, either between the two alternating treatments, or compared with controls given the two foods mixed together. The conclusion was that the growing birds appear to have the ability to compensate for short periods on amino acid imbalanced foods. Elkin *et al.* (1985) suggested that regulation of protein intake in choice feeding situations is only possible when the diet offered has adequate sulphur amino acids.

In a later study, Classen and Scott (1982) showed the ability of rearing and early laying White Leghorns pullets to select calcium to meet physiological requirements. The study demonstrated the ability of pullets to compensate for rearing deficiencies by increasing their calcium consumption when fed oyster shell on an *ad libitum* basis. It was also found that this compensatory ability also persisted after animals reached sexual maturity since calcium consumption became significantly higher on days when an oviposition occurred than when no eggs were laid. Furuse *et al.* (1993) compared the effects of dietary medium-chain triglyceride (MCT) and long-chain triglyceride (LCT) on short-term feed intake in chickens. They found that chicks preferred the LCT-supplemented diet over the diets containing MCT.

Such studies support the notion of "nutritional wisdom"—the idea that, if left to their own devices, animals select the diet optimal to their needs. There is some truth to the idea of nutritional wisdom—animals in general avoid poisons, and so on. Even relatively primitive creatures may modify their diets in accordance with circumstance—honey bees, for instance, rate dilute nectar more highly during hot days than during mild days, and preferentially communicate the location of dilute nectar sources to other bees in the hive (Gould and Grant Gould, 1995). However, the extent to which animals are nutritionally wise is disputable.

Newman and Sands (1983) also looked at nutrient selection by offering newly hatched layer chicks a choice between a low-lysine food and one with an excess of lysine. Although the birds ate some of the supplemented food, it was not enough to maintain a growth rate as high as those in a control group, which were given a single adequate feed. The two feed containers were kept in the same place throughout the 21-day experiment, but no colour cues were given and no separate training period was provided. Because of the small amounts of lysine involved, and its relative lack of colour and taste, it would be necessary to provide a strong cue such as food colour. In a second experiment, a low-lysine food was given in choice with L-lysine HCl, but although the birds ate some lysine, it was not enough to support normal growth (Newman and Sands, 1983). In this case it would be expected that there was sufficient contrast between the appearance and taste of the two foods on offer for adequate intake to occur. When D-lysine HCl was offered as a choice with a low-lysine food, the birds ate some, suggesting that D-lysine triggers a receptor mechanism even though it is unavailable for metabolism. Given a choice between L-and D-lysine, birds ate more of the L form. There is therefore some evidence of nutritional wisdom, but the evidence suggests that nutritional wisdom is insufficient, in itself, to give birds a properly balanced diet (and see Appleby *et al.*, 2004).

In two experiments Rose and Michie (1982) examined the food intakes and growth of choice-fed turkeys. The turkeys were offered a choice of: wholewheat and six balancer mixtures which were identical in composition except for the content of ground cereals; the wholewheat and four balancers varied only in their calculated metabolisable energy and the type of protein concentrate. Turkeys fed on balancers with a high content of white fishmeal ate more wholewheat and correspondingly less balancer than the turkeys offered balancers with high meat and bone meal content. Also, they found that the ME content of the balancer did not affect the food intakes of the turkeys over the total feeding trial. In addition, a higher proportion of barley in a balancer produced increased wholewheat intake when birds were introduced to a choice-feeding regime.

Emmerson *et al.* (1990) studied diet selection by turkey hens. Controls were given a complete feed containing 181 g/kg CP and 11.23 MJ/kg ME. A second high-protein feed treatment was created by adding high-protein ingredients (351 g/kg CP and 8.12 MJ/kg ME), and a third low-protein feed established by including low-protein ingredients. The choice-fed turkeys consumed 10% less food, 44% less protein, and the same amount of energy yet laid a similar number of eggs as those fed conventionally. In a further experiment of similar design (Emmerson *et al.*, 1991), there was no difference in egg production over a 20 week period. Broodiness tended to be reduced by choice feeding, and fertility and hatchability were lower. There was no significant difference in food intake, but choice-fed birds had a higher energy intake, as they selected a higher proportion of the low-protein food than was included in the control feed. Energy intake fell as the experiment progressed, presumably because of the rise in environmental temperature. Protein intake was about 35% lower for choice-fed birds, and the overall protein concentration of 110 g/kg diet was considerably below NRC (1994) recommendations. The fact that the protein content of the chosen diet increased throughout the experiment suggested that turkey hens fed single diets should be given feed with stepwise increases in protein content. The energy: protein ratio was 104.6 MJ/kg of protein compared with 62.1 MJ/kg for the control group.

It also frequently appears that food particle size influences food selection in poultry. Savory (1974) conducted an experiment in which newly-hatched hybrid and brown Leghorn chicks fed on diets in either pellet or mash form. The mash was made by regrinding pellets. During the experiments no chicks died over the first fifty days in any treatments, although thereafter mortality was seen among hybrids and Leghorns fed on mash and in hybrid fed on pellets: birds also showed symptoms of fowl paralysis. Over the first forty days, birds offered a choice of food types consistently preferred mash to pellets.

A subsequent study looked at the conditioning effects of wholewheat diets. Covasa and Forbes (1993a) examined the role of prior exposure to wholewheat on the subsequent choice made by broiler chickens between wholewheat and a compound feed. They reported that the effect of prior exposure was related to the age of birds at training and/or to the interval between learning and testing. Consequently, learning was an important process in making nutritionally appropriate choices when wholewheat was used. They also examined whether choice feeding could be influenced by the level of feed deprivation of chickens and by the length of time that birds had previously been exposed to wheat. They found that the selection of feed by chickens was greatly influenced by the type of feed to which they had previously been exposed (Covasa and Forbes, 1993b). Still later experiments studied female broiler chickens given various types of training to familiarise them with wholewheat and their subsequent selection between wholewheat and a standard grower food. The authors concluded that choice-fed chickens required no special training when wholewheat was used, provided that both foods types were offered from an early age (Covasa and Forbes, 1996).

It is known that up to about 14 weeks of age, growing pullets require protein only for feather development and a relatively slow rate of muscle deposition. However, as development continues there is rapid development of the ovaries and oviducts, which it is assumed requires increased demand for protein. Consequntly, protein intake, in a choice-feeding situation should increase as observed by Scott and Balnave (1989) who noted a significant increase in the protein content of food consumed by birds approximately 2 weeks before the onset of lay when birds are free to select their diets. Once they are in full lay, the birds are capable of choosing a balanced diet when given the opportunity.

Yo *et al.* (1997) studied the effect of corn particle size (either ground, cracked, or presented as wholegrains) and a protein concentrate (43.7 % CP) on the feed choice of broilers aged 2 weeks. They found that when corn was fed as a wholegrain, the birds significantly increased protein concentrates in their diets (35.1%) than with the cracked corn (29.3 %) or ground corn (29.1 %). Particle size of the concentrate was also a factor, since presenting the concentrate as pellets resulted in a significantly higher concentration in the diet (32.7 %) than when mash concentrate was fed (29.6 %). However, it was observed that live body weight at 4 and 6 weeks of age was not significantly affected by feed texture: although corn offered as wholegrains or concentrate as pellets did induce a significant improvement in feeding efficiency. They showed that there was rejection during the first 24 h when the form of the concentrate (mash to pellets) was changed, with about 3 days needed to fully adapt to the new size of the concentrate.

While examining pelleted and whole grain feeds Olver and Jonker (1997) considered the effects on growth, carcass composition or profitability of older birds. They found no significant differences between choice treatments and the pelleted control diet with regard to body weight, feed consumed, feed efficiency, carcase, ash, dressing percentage, or mortality. However, they did find that choice-fed broilers who received their energy source as wholegrains had larger gizzards, while the higher-protein diets (50 / 50) resulted in higher carcase moisture and protein but lower carcass fat than the broilers fed the pelleted control diets. The conclusion was that the main advantage of choice feeding appears to be in economic savings afforded by using wholegrain as an energy source.

Erener *et al.* (2003) investigated wholewheat based diets and looked at how wholewheat feeds affected performance of male broiler chickens. A total of 480 one-week-old male broiler chickens of a commercial breed were fed with the standard compound feed (CP) for 1 week. Subsequently, the male chicks were allocated randomly to four treatment groups: 1) control; 2) compound feed and wholewheat mixture (MF); 3) free-choice between compound feed and wholewheat in separate troughs (FCF); and 4) standard compound feed for the first 18h and wholewheat for the remaining 6h (SF). The FCF treatment increased live weight and weight gain as compared to MF and SF treatments. Feed conversion ratios (FCR) of FCF treatment birds were higher than those of the control. Full gut weight, abdominal fat, empty gizzard weight and weight of edible inner organs were all increased by choice feeding treatments in comparison to control birds. The results suggested that FCF method can be used effectively with broiler chicks. They specifically concluded that "feeding wholewheat decreased skeletal problems and wholegrain diets increased gizzard size. Feeding wholegrain and mash supplements caused at least a temporary loss in growth rate and feed efficiency but in some cases improved bird health."

Under normal conditions laying hens are fed a mash diet. The use of wholegrain would not only save the energy cost of grinding and mixing but would also be accompanied by increased food utilisation efficiency. Indeed, McIntosh *et al.*(1962) showed that grinding or pelleting wheat, barley, oats or maize did not result in a consistent increase in the metabolizable energy of poultry feed. They further showed that wholewheat yielded more metabolisable energy than ground or pelleted wheat in two out of three experiments. This is probably a direct consequence on the increased feed utilization efficiency with the intake of wholegrain (Henuk and Dingle, 2002). When Emmans (1977) offered hens either a complete mash or a choice between the complete diet and ground barley, no differences in performance of the birds was found between the two treatments. Karunajeewa (1978) fed laying hens complete mash diets, either barley-or wheat-based, or a choice between the wholegrains and a concentrate mixture. Hens receiving wheat laid better than those fed barley, but the hens receiving a choice laid heavier eggs and consumed 11% less food than those given the complete diets. In addition, diet selection studies of lay hens by Mongin and Sauver (1979) showed that hens increase their calcium intake when ovulation is about to occur. Hughes and Wood-Gush (1971b) had previously suggested that calcium appetite appeared to be a learned response and that the laying hen has the ability to selectively consume calcium to meet maintenance and production requirements.

An experiment carried by Olver and Malan (2000) showed that between 16 and 80 weeks of age, the hens offered a choice did not lay more eggs, nor did they consume more food than those fed a complete mash diet. However, choice-fed hens laid heavier eggs and eggs with thicker shells than those fed the complete diet. The heavier egg size of the choice-fed hens accounted for the better food conversion ratio obtained by these hens compared to those fed the complete diet. These results are at variance with the finding that increased protein intake results in heavier eggs (Scott *et al.*1982). However, both Blair *et al.* (1973) and Karunajeewa (1978) reported heavier eggs from choice-fed hens that consumed less energy and protein. Olver and Malan (2000) also reported a higher calcium intake by choice-fed hens than those fed a mash diet. This was coupled with differences in eggshell thickness, which indicated that the increased egg mass was due to increased calcium intake. The Haugh unit scores of eggs did not differ between diets, but the yolk colour of eggs laid by choice-fed hens was darker than that of eggs laid by hens fed the complete mash diet.

Apparently hens are in many cases able to adapt their feed intake to their requirement both quantitatively (amount of feed ingested) and qualitatively (level of protein, energy, minerals etc.) (Burel *et al.*1999). However, this is not the case under all conditions. Effects of bird holding, food presentation, and food choice conditions were simultaneously examined by Dana and Ogle (2002), who evaluated how scavenging impacted the diet selection and comparative performances of Rhode Island Red and Fayoumi breeds of chicken. Scavenging did not appear to change the pattern of diet selection, with approximately 90% of the daily intake of both confined and scavenging birds under choice feeding consisting of maize. The efficiency of feed utilization and nutrient intake were also similar among groups. In relation to differences between breeds, Fayoumi were more efficient in terms of feed conversion, although the egg production performance of the two breeds was not significantly different. Overall, scavenging hens had a significantly lower egg production than the birds under confinement who were offered a choice of feeds. At the same time scavenging significantly increased the mortality rate among hens regardless of breed. The conclusion was that scavenging had adverse effects on bird performance and survival. In addition, both the scavenging and confined birds on choice feeding failed to eat sufficient to meet their protein, despite the provision of self choice feeds which provided a source of energy and protein.

Munt *et al.*(1995) examined presentation method (pellets or mash, or as separate ingredients presented on a free-choice basis) and whether this caused any differences in growth, carcase composition, or profitability in chickens. They found that birds given a free choice varied widely in the proportions of ingredients eaten during the first 56 h of the trial. Subsequently, the proportions consumed did not widely vary with birds given free-choice eating about half of their intake as wholewheat, one-third of as concentrate (high-protein meals plus vitamin and mineral premixes), and one-seventh as whole sorghum. By the end of the three-week trial, the average live body weights of the birds differed significantly according to method of feeding, with average weights in ascending order being observed for birds fed on pellets; mash; free-choice.

Kutlu and Forbes (1993) while looking at self-selection of ascorbic acid (AA) in coloured foods (red and green) by heat-stressed broiler chicks, found birds were unable to select AA when neither food was coloured. This phenomenon was still apparent even when food was presented continuously in the same positions in the cage. The conclusion was that chicks could only learn to associate the colour of the food with its AA content. However, the birds were able to select proportions of supplemented and unsupplemented foods appropriate for their needs, as influenced by environmental temperature.

Changes in metabolism appear to be the cue for behavioural modifications. Covasa and Forbes (1995) examined in two experiments the effects of corticosterone (CORT) on diet selection of broiler chickens, where they offered a choice of a high protein concentrate (381 g CP/kg, 17.5 MJ/kg ME) and wholewheat (113 g CP/kg, 15.9 MJ/kg ME) in relation to age. They found that daily intramuscular injections of 2 and 4 mg/kg of CORT for a 5 day period in both 2 and 5 week old chickens resulted in increases in total food, protein, and energy intakes. The result suggests that birds are able to detect metabolic changes caused by CORT administration and attempt to redress them by modifying their feeding pattern. The time course of the response of birds to these changes is age-related.

In a similar study, Malheiros *et al.* (2003) looked at free-choice between three diets (low protein, low lipid and low carbohydrate) in which only one specific macronutrient (protein, lipid, or carbohydrate), with 0, 30, or 45mg of corticosterone per kg diet, was given to male broiler chickens aged 21 days for two weeks. They also concluded that adding corticosterone to diets affects the free diet selection of male broiler chickens, as these chickens consumed a greater percentage of low-protein diet and less of a low-fat diet. Specifically it was found that the corticosterone-treated chickens took a longer time to make definite choices between the diets compared to unsupplemented control chickens.

Perhaps not surprisingly the composition of hydration fluids can also affect feeding behaviour. Engku and Forbes (1989) compared the effect of tap water with the effect of offering a 91.5 g/l solution of glucose on fluid intake, food intake and growth of individually-aged immature chickens of both layer and broiler strains. They found that glucose had no effect on fluid intake, but that it depressed food intake to give equal total energy intakes for each treatment. The glucose resulted in a reduction of body weight gain and an increase in carcase fat content, yielding no difference to total carcase energy. Further experiments showed that, in the low-protein glucose-treatment diet, food intake was depressed but total energy intake and carcase energy were not significantly affected, while, with the high-protein diet, glucose did not depress food intake but did increase total energy intake and total body fat. They concluded that provision of extra energy in glucose solution depresses food intake when the resultant energy: protein ratio becomes limiting. With a higher-protein diet, or with birds that have lower protein requirements, glucose solution does not depress food intake, and increased fat deposition occurs.

In a series of reports Shariatmadari and Forbes (1990, 1991; 1993) showed a linear increase in protein deposition with dietary protein content up to 280 g/kg with broilers, and 225 g/kg with layers. Under free-choice diet regime, birds of both types grew at a rate that was not significantly different from birds fed on diets with lower protein content and that gave maximal growth when administered singly; apparently the birds made an appropriate choice within the different diet regimes. When both diets had higher protein content than the optimum, birds ate mostly from that closer to the optimum. They suggested that growing chickens can match their protein intake closely to their requirements when given a pair of diets that allows this; additionally if both diets provide better or poorer performance conditions compared to an optimal diet the birds will select the diet closest to the optimum. It was also shown that broilers on split diets could regulate their intake and grew as well as those given free-choice.

However, Farrell *et al.*(1981) carried out a feeding experiment comparing a commercial layer diet and three free-choice diets consisting of shell grit, a protein source and one of three energy sources: maize (100%) ; maize (60%) plus cassava (40%) ; and maize (94%) plus palm oil (6%). Although they found that feed and energy intakes were significantly higher on the commercial diet and lower on the maize and cassava mixture than the other treatments, there was no significant difference for protein intake. In addition, it was noted that egg production and egg weight were similar across the treatments, although the gross efficiency of feed conversion to egg mass and cost of production were much higher on the commercial diet.

The available evidence suggests that laying hens are less able than broilers to balance their protein intake when offered high-protein and low-protein foods. This may be partly explained by the fact that mature birds learn more slowly than rapidly-growing ones (Forbes and Shariatmadari 1994). It is frequently observed that broiler chickens make a sensible choice when given the option of choosing between diets differing in protein quality. For example, Gous and Swatson (2000) showed that broiler chickens, provided with two or three foodstuffs containing just one protein source, on a free-choice basis will effectively select a combination that maximizes their biological performance.

Finally with respect to diet selection, Cumming (1992) demonstrated quite significant genetic differences in the ability of different strains to adapt to free-choice diets. Egg-type stocks appear to adapt quicker than broiler strains. It also seems that there are major differences between adults of layer strains in adapting to free-choice feeding. For example, it was found that brown egg layers adapt more readily than white or tinted egg layers. Yet observations showed that all Australian strains of commercial layers and broilers learn rapidly (in ten to fourteen days) to quite accurately balance both their energy and protein intakes in a manner that maximize production while also as an aside optimising economic returns.

2.6 Effect of Feed Restriction on Broiler Performance

Under a variety of restricted feeding conditions there have been numerous observations that bird development and behaviour is significantly impacted. Savory and Mann (1999) observed that stereotypical behaviour in birds (such as pecking after feeding) is influenced by meal size: typical modifications included increased pacing before feeding time, increased drinking and pecking at non-food objects after feeding. In broiler chickens of 8 and 14 weeks of age, caged individually provided with 2 meals daily at 9.00h and 16.00h, it was found that as meal size increased, the proportion of time spent in object pecking after feeding increased and standing time decreased. There were no other significant effects of meal size on post-feeding behaviour.

Fontana *et al.* (1992) had earlier shown that early developmental feed restriction programmes imposed on broilers reduced consumption of starter diets (by 22% on average) compared with control birds. It has also been widely seen that energy restriction causes a reduction in metabolic energy loss, which subsequently leads to reduced maintenance costs

In respect of biometric relationships, Jahanian *et al.* (1994) tried to predict the effect of severity of diet dilution (energy and protein) and duration of early developmental feeding restrictions on feed intake, body weight gain and feed conversion ratio of male broiler chickens. In this experiment, day-old male Ross broiler chickens were used in a 2 × 4 factorial arrangement with factors being: severity of diet dilution (25 and 50 percent ground rice hulls added to diets) and duration of early feed restriction (0 (controls), 3, 6 and 9 days). All the birds began on a standard starter diet up to age 7 days, at which time they were transferred to described treatment blocks. Results indicated that during the period of feed restriction (at 8–17 days of age), food consumption of restricted chickens were significantly less than that of the controls. Consequently, during the period of feed restriction, body weight gains of restricted chickens were significantly different from that of the controls. However, the final body weight gains of all birds were similar even given the fact that the feed conversion ratio (FCR) of the restricted chickens was significantly less than that of the controls.

Apparently qualitative feeding restrictions also impact behaviour in addition to quantitative restrictions. A study looking at qualitative rather than quantitative restriction by Savory *et al.* (1996) investigated the possible welfare benefits of alternative approaches. In one experiment, different diet dilutions, low-protein, and appetite-suppression treatments were compared on chicks from 2 to 6 weeks of age. In a further experiment, four diluted diets and one appetite-suppression diet were compared with an *ad libitum* control and two levels of quantitative restriction diets on chicks from 2 to 10 weeks of age. They measured growth, feed intake, excreta production, digestibility, behaviour, and blood indices of stress. It was found that the different restriction regimes led to changes in weight gain uniformity and excreta production. The researchers concluded that although the qualitative regimes appear to suppress abnormal oral behaviour, the treatments did not alter the generally increased activity that is normally associated with suppression of avian growth rates.

In a similar experiment, Kubikova *et al.* (2001) observed the behavioural, endocrine and metabolic effects of food restriction in 13-week-old broiler hens. The researchers provided two quantitative diets (the daily ration recommended by the breeding company and twice that amount) and one *ad libitum* qualitative diet (diluted with 30 % hardwood sawdust) and compared the treatments to birds under an *ad libitum* feeding regime. The behaviour of qualitatively restricted hens was seen to be more consistent throughout the day, while quantitatively restricted hens provided with one daily meal showed significant diurnal variation in behaviour. In addition, the plasma corticosterone concentrations were increased in quantitatively feed restricted hens: the corticosterone concentrations of hens subjected to qualitative feed restriction was also lower, but still significantly higher in comparison to control birds, suggesting that even mild qualitative food restriction can be stressful.

Since broiler chickens have been selected for rapid weight gain they often appear to be continuously hungry. Under such circumstances the energy invested by broilers in obtaining food should remain unaffected by levels of feed restriction. Bokers *et al.*(2003) examined this hypothesis by measuring the maximum costs that birds of different body weights would be willing to experience for food rewards under conditions of varying feed restriction. They established two groups of 20 broiler chickens fed on 50 or 75% of the amount of feed a broiler would eat when fed *ad libitum*. Broiler chickens in the 50% group paid higher costs for food rewards and responded more rapidly to food presentation than the birds in the 75% group. The birds also showed frustration after the last food reward had been obtained, indicating that they were still hungry. The different levels of long-term food restriction also had an influence on bird body weight, as well as affecting how much work the birds participated in to gain food. Over the short term changing feeding restriction levels had no effect on behaviour.

It cannot be denied that feedings restrictions in broiler chickens have significant implications for bird welfare. Normal commercial feed restriction programmes usually consist of either feeding a fixed amount of food every day or every second day. This type of feeding restriction has been shown to cause stress that results in increased activity, aggression, stress hormone levels, and stereotypic behaviours. De Jong *et al.* (2003) examined the parameters for quantification of hunger in broiler breeders. For this experiment, they used 10 female Hybro G broiler breeders per treatment, which were subjected to different levels of feed restriction and it was assumed that this induced different levels of hunger. They found that with a restricted food intake, beginning at 1 week of age, broilers demonstrated significant changes in abdominal fat levels by the time the birds had reached market age. This finding was supported by other feeding restriction experiments carried out by Plavnik and Hurwitz, 1985; Plavnik *et al.* (1986) that showed significant improvements in feed efficiency could be attained along with a reduction in body fat. However, Summer *et al.* (1990) could not show advantages in terms of reduced abdominal fat for broilers restricted in feed intake from 7–14 days of age when compared with broilers that ate *ad libitum*. A similar result was reported by Deaton (1995), who observed that early feed restriction on broiler performance did not affect abdominal fat but did improve feed conversion.

Watkins *et al.* (1993) noted how amino acid content of feeds in conjunction with feeding regimes could modify performance parameters. In their experiment, male and female broiler chickens were used, and were fed on starter diets until either 0, 7, 14, or 21 days of age, and then switched to grower diets until 40 days of age, and on to finisher diets from 40 to 45 days of age. The diets contained 100, 110, and 120% of the suggested amino acid requirement of male broilers. The mean weight of broilers at 40 days was significantly reduced when broilers were placed on a grower diet at 0 days, although mean weight at 45 days was not significantly different among treatments. For females, birds placed on a grower diet at 0 days, their weight at 45 days was significantly less than that of females placed on a grower diet at 7 or 14 days. The result of the experiment clearly showed that changing diets at 14 days or earlier resulted in a linear increase in breast meat yield of males as amino acid content increased. However, changing diets at 21 days failed to produce changes in breast meat yield among males regardless of added amino acid content levels.

In relation to feeding regimes where feed skipping was employed, Leeson and Summer (1985) compared skip-a-day and fed every-day feed restriction on the performance of dwarf broiler breeders and their offspring. When birds were fed every day they became heavier and generally had longer shanks than those on skip-a-day feeding. In addition, Mench (1988) fed male broiler chicks either *ad libitum* or placed on skip-a-day feed restriction and observed an increase in male broiler aggressive behaviour in chicks on skip-a-day feed restriction regimes. In particular aggressive activity in the skip-a-day regime birds was increased on mornings of non-feeding: the behaviour decreased to its lowest levels after birds were switched to full feed for a period of 4 days. Finally, De Jong, *et al.* (2002) reported on the effect of initiation age of skip-a-day feeding restrictions on skeletal development in broiler males. The observations showed that starting a skip-a-day feeding program at 2, 4 or 6 weeks of age resulted in decreased shank, keel length and head width. Overall, evidence suggests that restricted diets have broadly negative impacts on performance and bird welfare.

2.7 Conclusions and Focus of Present Study

The fat dietary amounts within the first 10 days of chick development has a direct effect on the percentage of abdominal fat pad at 44 days of age (Brake *et al.*, 1993). Adding lard at a proportion of 7% decreased relative liver weight in birds given lower (3%) fat diets, as well as increasing fecal fat during the first 11 days (Latour *et al.*, 1994). Sheppard *et al.* (1980) also indicted that broiler relative liver weight is depressed between 1 and 22 days post-hatching, as dietary fat level are raised. Another study based on elicited broiler chicks, found that cholesterol Low density lipoprotein cholesterol (LDLC) and High density lipoprotein cholesterol (HDLC) concentrated between 14 and 42 days of age that varied with sex and age of the chicks and these levels did not relate to body weight (Peebles *et al.*, 1997a, 1997b). However, body weight in male broiler chicks is apt to increase at 3 or 7% constant levels of dietary fat. In addition, the young broiler chicks' utilization of fat is highly limited (Carew *et al.*, 1972), which suggests feeding no supplemental fat in the diet for chicks in the first 7 days of age produced birds with significantly less abdominal fat after birds reached 49 days of age (Hargis and Creger 1980). However, although there is a significant reduction in abdominal fat at 7 wks of age if the early diet contains 8% added fat, other higher fat treatments are more suitable over longer periods of time (Maurice *et al.*, 1982).

Many studies have indicted the general physiological inability of hatched chicks to absorb fat. This is often assumed to be due to incomplete physiological development of the younger birds. For example, the digestibility of fat in the first week for broiler breeder males is lower than in the second and third weeks of age. Broiler chicks in the first days of age could not digest oils; furthermore, two experiments demonstrated that apparent digestibility of fat is high in the first week of age, low in the second and higher after the third week of life. This result was supported by Noy and Sklan (1995), who reported the digestion and absorption of fats in chicks between (1–21 days) is only 85% by the time they reach four days old, but rapidly increases afterwards. It was suggested that lipases activity and bile salts production have reached sufficient levels by age 4 days (and see Freitas, 1999; Cancado, 1999).

The present study focuses upon the still poorly investigated early life stages of chicken nutrition in relation to relatively high fat supplementation and free-choice dietary feeding regimes. The feeding effects during early development are often recommended as an important area of investigation (Noy and Sklan, 2002; Sklan and Noy, 2000; Plavnik *et al.*, 1997; Baker and Han, 1994; Hewitt and Lewis, 1972). However, the present study is the first to examine broiler chicks' nutrition during the first developmental weeks, in terms of high fat and free diet selection. To this end, the study's first experiment specifically investigated the effects of both fat levels in diet and free diet selection on bird performance metrics, and subsequent experiments either built on the first's results or explored other hitherto non-investigated early bird developmental phenomena.

Chapter 3: The Effect of Different Fat Levels of Diets Offered in a Free-Choice Feeding Regime on Feed Selection by Broiler Chicks Aged From 1 to 12 Days

3.1 Introduction

The literature reveals that the overwhelming balance of evidence suggests that fat levels and diet selection regime can significantly influence poultry developmental performance. Several key studies bear witness to this. Fuller (2004), for example, reported that chickens, offered a choice of diets, will select between two or more feeds in an apparent attempt to balance their nutrient intakes. The apparent selection of particular diets closely matches the bird's optimal food requirements. Fuller's work extends the results of Hughes (1984) and others, to the effect that diet selection in birds is common, particularly in respect of balancing specific nutrients such as calcium and sodium. This balancing of nutrient intake appears to be achieved by an initial random sampling of food items presented, followed by more selective feeding on those food items that provide the most optimal levels of nutrients for the birds needs (Wood-Gush and Kare, 1966; Hogan, 1973; Hughes and Whitehead, 1979).

Preference tests have previously shown that fowl will select diets based upon a wide range of specific nutrients. These include essential elements like calcium (Mongin and Saveur, 1979), phosphorus (Holcombe *et al.*, 1976a), and zinc (Hughes and Dewar, 1971); particular vitamins such as thiamine (Hughes and Wood-Gush, 1971a); and certain protein levels (Holcombe *et al.*, 1976b). Further studies suggest that free-choice based feeding regimes may have some effect on bird body weights and a marked effect on female reproductive performance (McDonald and Emmans, 1980). The correlations between feeding preferences and growth rates of birds may offer an opportunity by which nutritive differences among feeds can be more easily assessed (Rose and Abbas, 1993)

Chicks rely heavily on yolk fat (Appleby *et al.* 2004; Forbes 1995; Freeman, 1965; Rogers, 1989; Broom, 1968) during the first few days of their lives. However, most current standard commercial starter diets contain low percentages of fat (approximately 4.6%) and high protein (approximately 24%), in addition to all essential nutrients.

Different approaches may be taken to test diet selection during early development. For this experiment, a free-choice feeding regime was used. Based upon the evidence presented above, the experiment followed the development of 1–12 day old chicks on 3 diets differing in fat content, to see if the birds would consume more of the higher fat level (8.0%) during the fist 6 days of their lives, and whether their choice would change to lower fat diets (4.6%) after the first 6 days.

If the results accord with the proposition that higher fat levels in diets causes increased ingestion, then it can be said there is strong evidence that brain development in chicks may be linked to changing feeding behaviour. The demonstration of an active choice would have an impact on the future welfare of chicks, specifically relating to the techniques used to cull chicks, as well as increasing future production by increasing the percent of fat in the standard commercial starter diets.

3.2 Hypotheses

The experiment investigated the hypotheses that very young chicks prefer high fat diets, and that older chicks prefer lower fat diets. If both hypotheses are true, chicks should consume more of a high fat diet (8.0%) during the first 6 days of their life and consume more a lower fat diet (4.6%) thereafter.

3.3 Experiment 1

The aim of this experiment was:

- To explore whether broiler chicks were able to perceive their energy requirement at different stages within their lifespan—especially within the first few days of their lives.

- To investigate birds' eating behaviour by measuring feed intake, and food choice.

3.3.1 Materials and Methods

3.2.1.1 Animals and feeds

Twenty, 1-day old male broiler chicks (Aviagen hybrid) were obtained from the Grampian Country Food Ltd., Glan Dwr Poultry Unit, Anglesey (Wales) and were housed in pens throughout the 12 days of the experiment. The chicks were provided free-choice of three starter crumb diets different in fat level (4.6, 6.0, and 8.0% Soya oil); the starter crumb diets were identical other than in their fat content (see Appendix 1).

3.3.1.2 Procedure

The broiler chicks were weighed and labelled with different colours; the latter for ease of identification. See Plate 3.1.

Plate 3. 1 Chicks with colour labels. Labelling comprised different position (head, neck etc.) and different colour (blue or red).

All birds were housed on a deep litter of wood shavings (8cm), with *ad libitum* feed and easy access to water. Three feeders were used and the height was adjusted daily to shoulder level of birds for easy access to feed and water. The positions of feed troughs were changed daily. The room was well ventilated and temperature controlled, an extra spot heater was also used during the first three days of the experiment to provide more heat for the chicks. The temperature was 29° C during the first 3 days, with a gradual decline of 1° C every 2 or 3 days thereafter, as recommended by commercial authorities (Ross, 2000).

A 24h/day lighting regime was used during the first week followed by 23h light:1h dark regime in the second week (typical of commercial broiler production systems).

3.2.1.3 Treatments

In this experiment twenty 1-day old male broiler chicks were given a choice of 3 diets over a 12 day period. The diets varied in fat levels: diet 1 (4.6 %), diet 2 (6.0%), and diet 3 (8.0%). See Box 3.1. The composition of diets is presented in Table 3.1 and Appendix 1. The fats in the diets came from soya oil. These diets were commercially obtained starter feeds for male broiler chicks from Grampian Country Food Ltd, Glan Dwr Poultry Unit, Anglesey (Wales). All diets were provided *ad libitum*. The physical properties of the feed pellets were standard across all 3 types of diet.

Box 3. 1. Treatment: feeding procedure; experiment 1.

	Treatment
Day	Free choice
1–12	Diet 1(4.6%fat), diet 2(6.0%fat), and diet 3(8.0%fat) starter crumb diet

Table 3. 1. Composition of the experimental diets (%).

Analyzed composition	Diet 1	Diet 2	Diet 3
Protein	24.1	23.7	23.2
Fat*	4.61	6.03	8.02
Calcium	1.04	1.03	1.01
Phosphorus	0.82	0.81	0.79
Crude fibre	3.01	2.96	2.90
Ash	6.59	6.49	6.35

*: Soya oil

3.3.1.4 Measurements

3.3.1.4.1 Feed intake

Feed troughs were weighed daily at 8:30 am.

3.3.1.4.2 Behavioural recording

The behaviour of the test chicks was observed according to procedures of Prayitno (1994), with some modification. The effects of three different diets on subsequent behaviour were observed and recorded for each individual bird by ticking the appropriate behavioural box (see Table 3.2) for the response observed every 5 minutes within the hour between 09:00 am and 18:00 pm on a daily basis. Behavioural response descriptions are presented in Appendix 2. Behavioural responses measured were as shown in Box 3.2.

Box 3. 2. Behavioural responses.

Behavioural Responses	
Sitting	Standing
Sleeping	Walking
Aggression	Floor Pecking
Body/Wing Stretching	Body Grooming
Drinking(Sitting/Standing)	Feeding(Sitting/Standing)

Table 3. 2. Behavioural record chart 1.

Bird No	FSt (1,2,3)	FSi (1,2,3)	DSt (1,2,3)	Dsi (1,2,3)	S	St	Si	W	W/BS	A	FP	BG
1												
2												
3												
4												
5												
6												
7												
8												
9												
10												
11												
12												
13												
14												
15												
16												
17												
18												
19												
20												

F: Feeding; D: Drinking; S: Sleeping; St: Standing; Si: sitting; W: Walking; W/BS: Wing and Body Stretching; A: Aggression; FP: Floor Pecking; BG: body Grooming

3.3.1.5 Statistical analysis

The data analysis was spilt into two parts. First, the data were analysed for the whole period (12days) and then split into two groups, group1 (the first 6 days) and group 2 (the last 6 days) and analysed separately.

All data were analysed using Minitab 13's General Linear Model (GLM) module to conduct analyses of variance (ANOVAs). .

Raw data of behaviours were transformed using a square root transformation $\sqrt{(x + 0.5)}$ to ensure normality and equality of variances. The dependent variables for the ANOVAs were behaviour (sitting, sleeping, etc.—see Box 3.2), and diet (low fat, medium fat, and high fat); a separate ANOVA was conducted for each (see

Box 3.2). The independent variable was time (measured in two ways: day and hour)). All ANOVAs were one-way repeated measures.

3.3.2 Results

3.3.2.1 Feed intake of whole periods (12 days)

A summary of results are presented in Table 3.3. Statistical analysis showed no significant differences between intakes of any of the three diets during the whole periods (12 days)

Table 3. 3. Mean of feed intake of three diets over the whole period consumed by broiler chicks.

Diet	Mean (g/bird)
Diet 1	11
Diet 2	9
Diet 3	16
SE	± 7.2

[a,b] Mean values not sharing a common superscript letter are significantly different ($p <$ .05); n=2

3.3.2.2 Feed intake of group1 and 2

In this part of the analysis the data was split into 2 groups (group 1: days 1–6; group 2: days 7–12) and independently analysed. A summary of results for group 1 (1–6 days) is presented in Table 3.4. Diet type was found to be significant ($p < .05$). The results showed no significant differences recorded between diet1 and diet2. However, a significant difference ($p < .05$) between diet 3 and diet 1 where the mean of diet3 was 14g compared to 4g for diet1. A significant difference was also recorded between diet 3 and diet 2 (14g and 2g respectively).

Table 3. 4. Mean feed intake of the three diets over the first 6 days by broiler chicks.

Diet	Mean (g/bird)
Diet 1	4^{a}
Diet 2	2^{a}
Diet 3	14^{b}
SE	± 3.9

[a,b] Mean values not sharing a common superscript letter are significantly different ($p < .05$)

A summary of results for group 2 (7–12 days) is presented in Table 3.5. Statistical analysis shows no significant differences detected between intakes of any of the three diets during this time period.

Table 3. 5. Mean feed intake of three diets over the last 6 day consumed by broiler chicks.

Diet	Mean (g/bird)
Diet 1	18
Diet 2	15
Diet 3	17
SE	± 4.7

($p < .05$)

3.3.2.3 The behaviour of broiler chicks

Significance ($p < .05$) levels and total mean behavioural responses observed daily and hourly, for all bird behaviours are presented in Tables 3.6 and 3.7 respectively.

Table 3. 6. Daily mean behavioural responses* for days 1–12.

Behaviour	Day											
	1	2	3	4	5	6	7	8	9	10	11	12
Feeding Standing of diet 1 (b/h)	0.80	0.77	0.80	0.74	0.73	0.83	1.00	0.90	0.79	0.85	0.87	0.95
Feeding Standing of diet 2 (b/h)	0.79	0.75	0.75	0.78	0.80	0.77	0.83	0.85	0.94	0.86	0.83	0.99
Feeding Standing of diet 3 (b/h)	1.72	1.36	1.31	1.22	1.20	1.12	0.99	1.15	0.96	1.11	0.96	0.90
Feeding Sitting of diet 1 (b/h)	0.71	0.71	0.71	0.71	0.71	0.75	0.74	0.71	0.71	0.71	0.72	0.73
Feeding Sitting of diet 2 (b/h)	0.72	0.71	0.71	0.71	0.72	0.73	0.72	0.71	0.71	0.72	0.71	0.73
Feeding Sitting of diet 3 (b/h)	0.72	0.73	0.71	0.74	0.83	0.80	0.73	0.71	0.71	0.73	0.72	0.71
D Standing (b/h)	1.15	1.07	1.03	0.88	0.96	1.01	1.00	1.12	1.02	1.06	1.14	1.13
D Sitting (b/h)	0.75	0.75	0.73	0.71	0.74	0.73	0.72	0.71	0.73	0.71	0.75	0.73
Sleeping (b/h)	1.73	2.26	2.44	2.74	2.66	2.48	2.30	2.37	2.40	2.38	2.52	2.50
Standing (b/h)	1.21	1.10	1.04	0.96	0.91	0.84	0.88	0.92	0.90	0.91	0.99	0.91
Sitting (b/h)	1.44	1.59	1.56	1.23	1.30	1.30	1.32	1.29	1.56	1.41	1.28	1.31
Walking (b/h)	1.11	1.03	0.86	0.82	0.84	0.81	0.88	0.86	0.85	0.81	0.80	0.78
Wing/Body Stretching (b/h)	0.76	0.78	0.81	0.85	0.82	0.89	0.90	0.86	0.86	0.87	0.81	0.87
Aggression (b/h)	0.78	0.73	0.76	0.79	0.76	0.79	0.80	0.79	0.77	0.78	0.72	0.74
Floor Pecking (b/h)	1.21	0.99	0.98	0.94	0.92	1.04	1.20	1.10	1.01	1.07	1.04	0.99
Body Grooming (b/h)	0.68	0.72	0.71	0.74	0.88	1.02	1.11	1.08	1.05	1.12	1.05	1.04

*Values are transformed data; ($p < .05$); b: bird; h: hour

Table 3. 7. Hourly mean behavioural responses* between 09:00 am and 18:00pm.

Behaviour	Hour								
	9	10	11	12	13	14	15	16	17
Feeding Standing 1 (b/h)	0.92	0.82	0.84	0.85	0.80	0.85	0.86	0.84	0.84
Feeding Standing 2 (b/h)	0.87	0.85	0.82	0.83	0.78	0.87	0.83	0.83	0.85
Feeding Standing 3 (b/h)	1.28	1.03	1.14	1.16	1.20	1.12	1.06	1.13	1.18
Feeding Sitting 1 (b/h)	0.73	0.73	0.71	0.71	0.72	0.72	0.72	0.72	0.72
Feeding Sitting 2 (b/h)	0.72	0.72	0.72	0.71	0.71	0.73	0.73	0.72	0.71
Feeding Sitting 3 (b/h)	0.72	0.75	0.75	0.73	0.73	0.75	0.74	0.73	0.73
D Standing (b/h)	1.10	1.15	1.06	1.01	0.98	1.03	1.06	1.02	1.08
D Sitting (b/h)	0.73	0.73	0.74	0.71	0.75	0.72	0.72	0.73	0.75
Sleeping (b/h)	2.43	2.44	2.37	2.43	2.46	2.38	2.43	2.39	2.34
Standing (b/h)	0.89	0.90	0.94	0.97	0.95	1.04	0.99	0.98	0.96
Sitting (b/h)	1.48	1.33	1.41	1.37	1.47	1.39	1.35	1.34	1.29
Walking (b/h)	0.84	0.86	0.86	0.86	0.89	0.85	0.82	0.87	0.91
Wing/Body Stretching (b/h)	0.77	0.87	0.87	0.85	0.85	0.81	0.83	0.88	0.83
Aggression (b/h)	0.76	0.76	0.75	0.77	0.77	0.74	0.78	0.78	0.78
Floor Pecking (b/h)	1.02	1.00	1.03	1.00	0.99	1.03	1.08	1.05	1.08
Body Grooming (b/h)	0.94	0.99	0.94	0.94	0.82	0.95	0.97	0.98	0.93

*Values are transformed data; ($p < .05$); b: bird; h: hour

3.3.2.3.1 Feeding standing of diets 1, 2 and 3

Figure 3.1 shows there was significant increase in standing feeding behaviour associated with diet 1 on day 7 compared with days 1, 2, 3, 4, 5, 6, 8, 9, 10, and 11. However, no significant differences were found between days 7 and 12. For feeding standing behaviour associated with diet 2, no significant differences were detected between days 8, 9, and 10; however, there were significant differences between days 9 and 12 (0.85 and 0.99 respectively) (Figure 3.2). Mean feeding standing behaviour associated with diet 3 on day 1 (1.72) was significantly different compared with all other days (Figure 3.3). In general, mean responses of feeding of diets 1 and 2 showed roughly similar trends, tending to roughly increase throughout the experimental period. However, the mean of feeding standing of diet 3 was higher at the beginning compared with the end of the experimental period, showing a general decreasing observation of the behaviour.

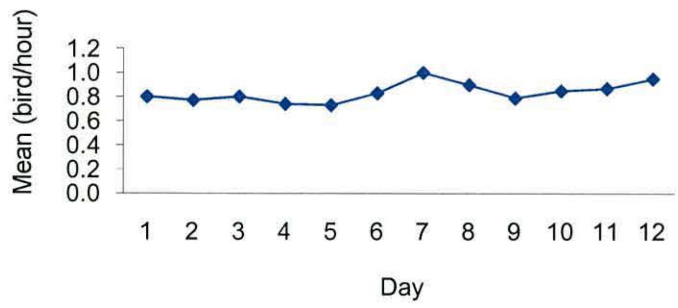

Figure 3. 1. Mean of feeding when standing: diet 1.

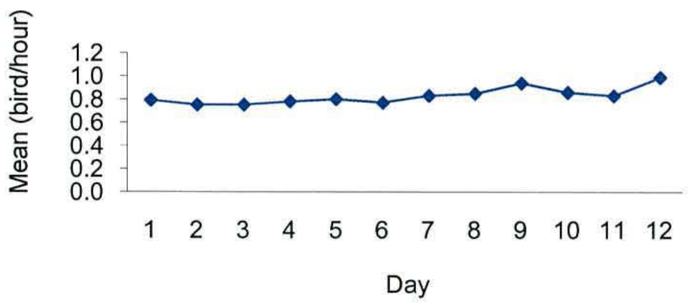

Figure 3. 2. Mean of feeding when standing diet 2.

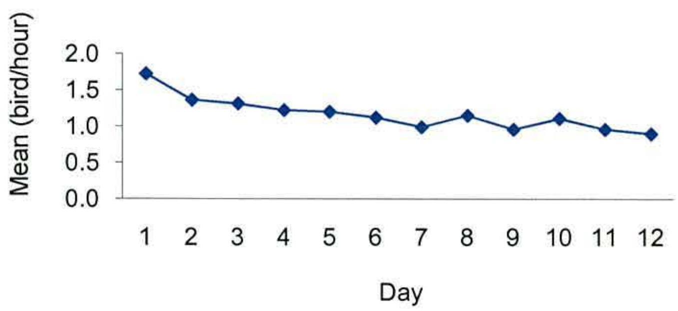

Figure 3. 3. Mean of feeding when standing: diet 3.

Statistical analysis showed no significant differences between feeding standing of diets 1 and 2. However, a significant difference ($p < .05$) was recorded between feeding standing of diets1 and 3, and between feeding standing of diets 2 and 3, where the means of feeding standing of diet1, 2 and 3 were 0.85, 0.84 and 1.14 respectively. See Figure 3.4 and Table 3.8.

The observation of hourly feeding while standing behaviour showed a similar pattern, with hourly observation of feeding while standing on diet 3 higher than on the other two feeds (Figure 3.5)

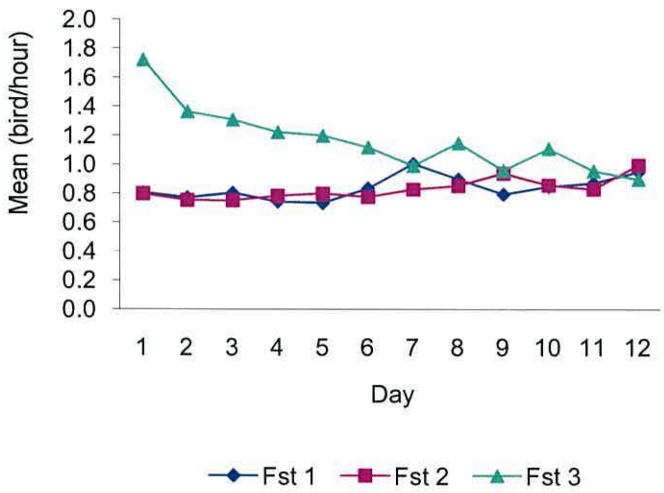

Figure 3. 4. Mean daily feeding standing (Fst) behaviour of all diet treatments.

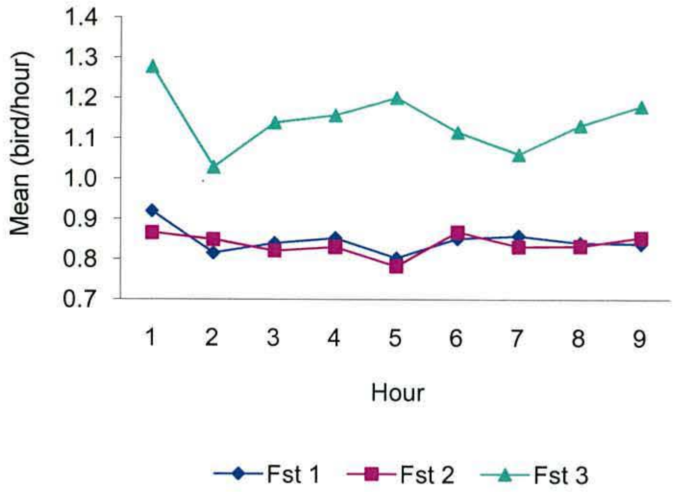

Figure 3. 5. Mean hourly observation of feeding standing (Fst) behaviour associated with all diet treatments.

Table 3. 8. Total observation of feeding standing behaviour associated with each diet.

Diet	Mean (b/h)
Diet 1	0.85[a]
Diet 2	0.84[a]
Diet 3	1.14[b]
SE	± 0.001

[a,b] Mean values not sharing a common superscript letter are significantly different ($p < .05$); b:bird; h: hour

3.3.2.3.2 Feeding sitting of diets 1, 2 and 3

Mean feeding sitting of diet 1 responses were similar over the first 5 days, then increased on days 6 and 7 (0.75 and 0.74 respectively). However, on days 8–10 this behaviour decreased, but subsequently increased over the next two days, reaching a peak on day 12 (0.75) (Figure3.6).

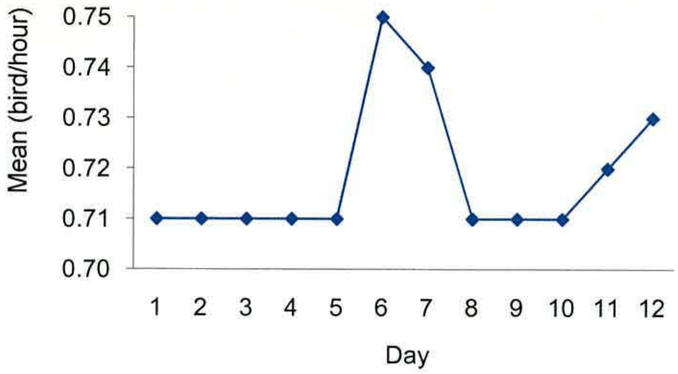

Figure 3. 6. Mean of feeding when sitting: diet 1.

Figure 3.7 shows the mean of feeding sitting of diet 2 reached a peak on days 6 and 12 (0.73). The mean of feeding sitting of diet 3 on day 5 was 0.83 and was significantly different from all other days except day 6 (0.80) (Figure 3.8).

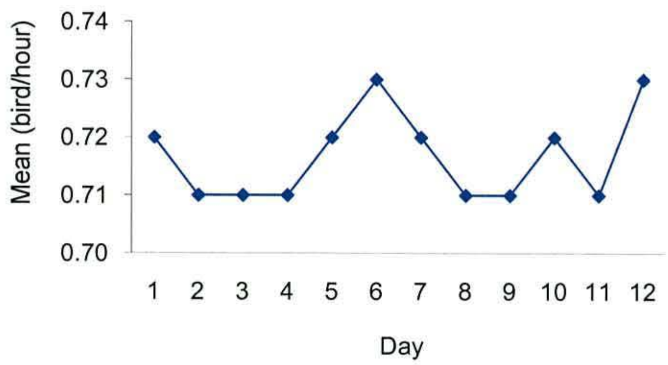

Figure 3. 7. Mean of feeding when sitting: diet 2.

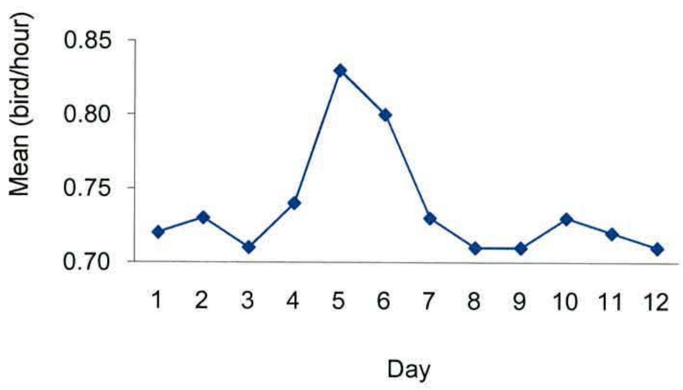

Figure 3. 8. Mean of feeding when sitting: diet 3.

At the beginning of the experiment (days 1–4) birds spent the same amount of time feeding while sitting on each diet type. However, during days 5 and 6 the birds spent more time feeding while sitting on diet 3. For day 7 onwards, subsequent feeding while sitting behaviour was the same on all diets (Figure 3.9). The time spent per hour was more erratic across the three diets, with the feeding while sitting behaviour associated with diets 1, 2 and 3 most prominent on days 1 and 2, 6 and 7, and 2, 3, and 6 for each diet respectively (Figure 3.10).

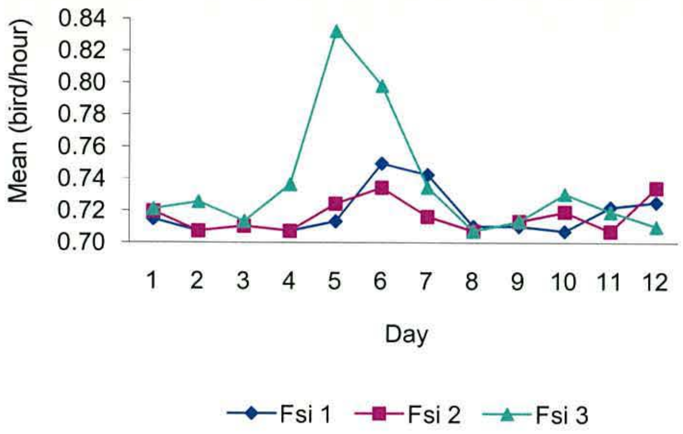

Figure 3. 9. Mean daily feeding sitting (Fsi) behaviour of all diet treatments.

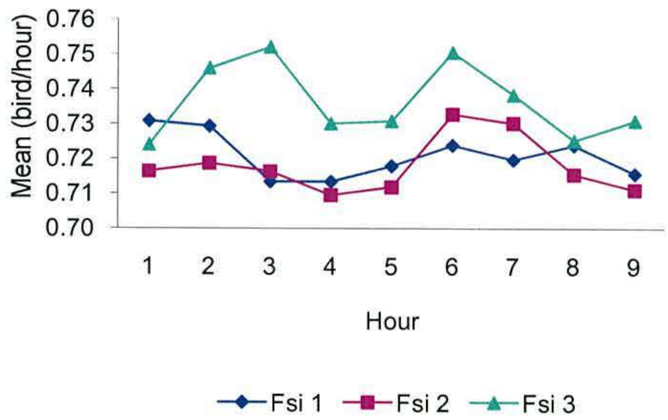

Figure 3. 10. Mean hourly observation of feeding sitting (Fsi) behaviour associated with all diet treatments.

Table 3.9 shows that there were significant differences ($p < .05$) between feeding sitting of diets 1 and 2 compared with feeding sitting of diet 3, with means of 0.72, 0.72 and 0.74 respectively. However, no significant differences were found between feeding sitting of diets 1 and 2.

Table 3. 9. Total observation of feeding sitting behaviour associated with each diet.

Diet	Mean (b/h)
Diet 1	0.72[a]
Diet 2	0.72 [a]
Diet 3	0.74 [b]
SE	± 0.003

[a,b] Mean values not sharing a common superscript letter are significantly different (p < .05); b:bird; h: hour

3.3.2.3.3 Drinking (standing and sitting)

The mean of drinking standing was 1.15 on day 1 and no significant difference was detected between day 1 and all other days except days 4 and 5 (0.88 and 0.96) (Figure 3.11).

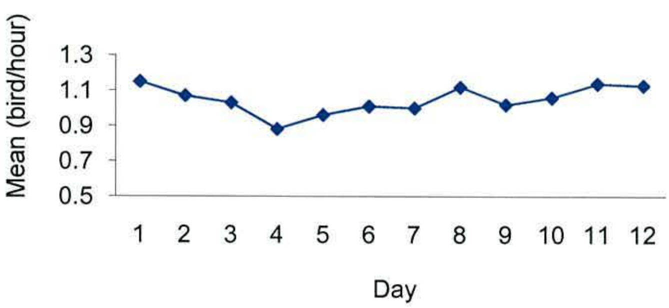

Figure 3. 11. Mean of drinking when standing.

The mean of drinking sitting were highest (0.75) on day 1, 2 and 12. However, days 4, 8, and 10 showed the lowest incidence of drinking sitting behaviour (0.71) (Figure 3.12).

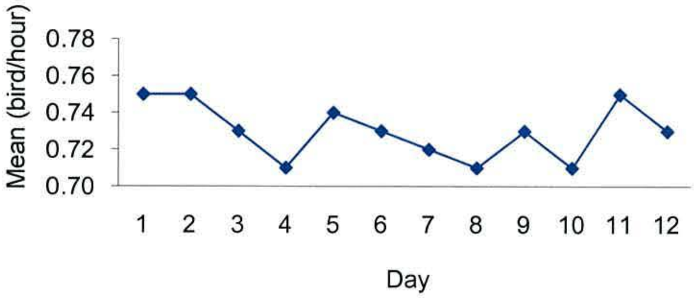

Figure 3. 12. Mean of drinking when sitting.

3.3.2.3.4 Sleeping

Less sleeping was observed on day 1 (1.73). This was significantly different from all other days (Figure 3.13).

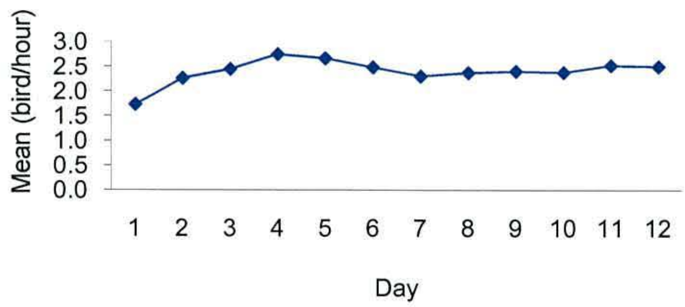

Figure 3. 13. Mean of sleeping.

3.3.2.3.5 Standing, sitting, and walking

The mean standing behaviour was highest on day 1 (1.21) and was significantly different from all other days except day 2 (Figure3.14).

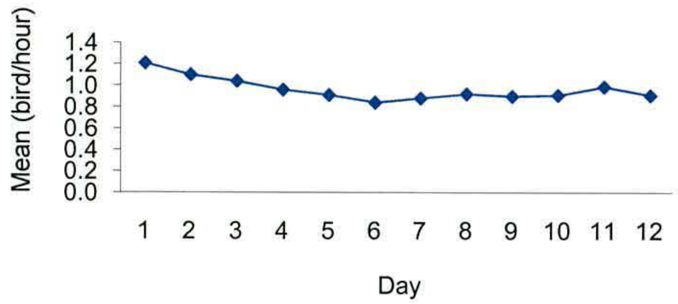

Figure 3. 14. Mean of standing.

The highest mean sitting response was 1.59 on day 2, but there was no significant difference between days 1, 2, and 3. There were significant differences between day 2 and days 4–12 (Figure3.15).

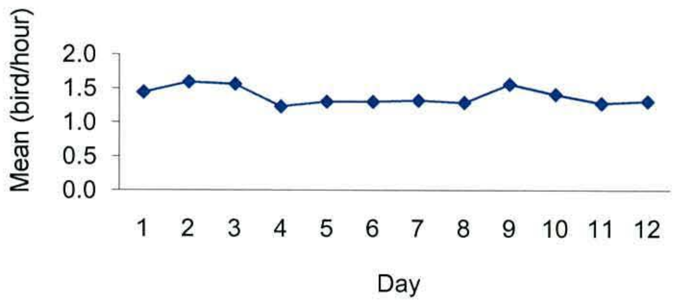

Figure 3. 15. Mean of sitting.

Walking behaviour on day 1 (1.11) and day 2 (1.03) was significantly higher than all other days (Figure 3.16).

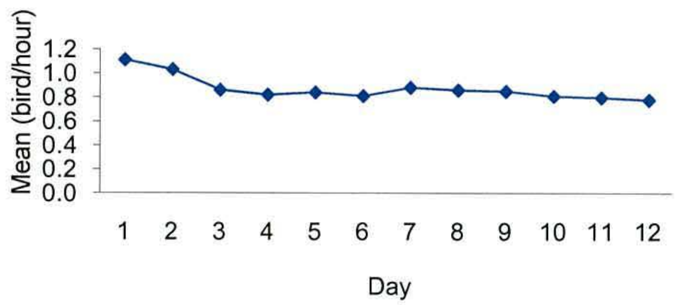

Figure 3. 16. Mean of walking

3.3.2.3.6 Wing/body stretching and aggression

On day 7, the mean wing/body stretching response was 0.90. This was significantly different from responses on days 1, 2, 3, and 11(Figure 3.17).

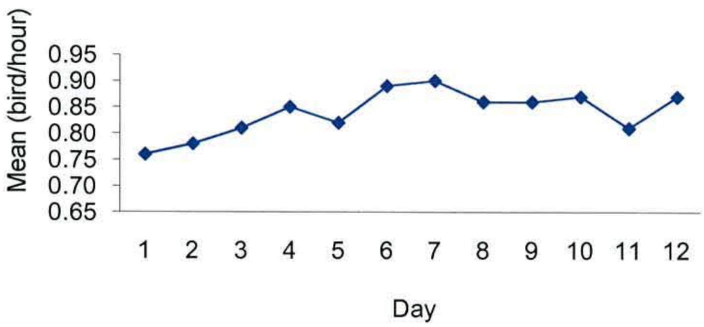

Figure 3. 17. Mean of wing or body stretching.

Figure 3.18 shows that most aggression was observed on day 7 (0.80). There were significant differences between day 7 and days 2, 11, and 12.

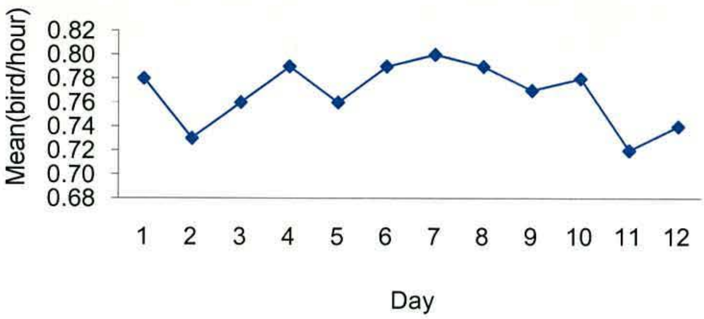

Figure 3. 18. Mean of aggression.

There was, incidentally, no significant difference in level of aggression for any of the three diets.

3.3.2.3.7 Floor pecking and body grooming

Figure 3.19 shows that floor pecking was higher on day 1 (1.21) than on days 2, 3, 4, 5, 9, and12. There were no significant differences between days 1, 6, 7, 8, 10, and 11.

The body grooming was least observed on day1 (0.68). This was statistically significant from days 5–12. There were no significant differences between day 1 and days 2–4 (Figure 3.20).

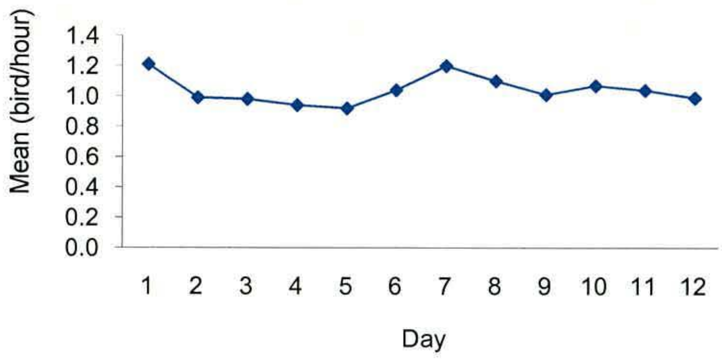

Figure 3. 19. Mean of floor pecking.

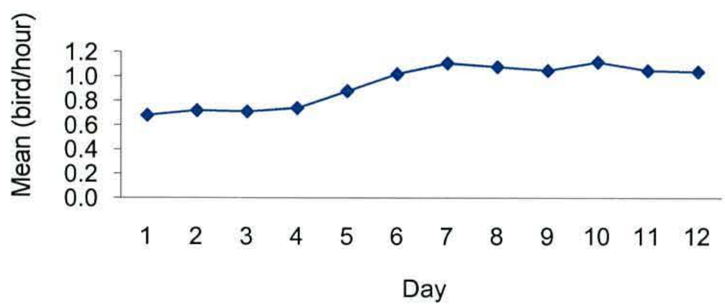

Figure 3. 20. Mean of body grooming.

3.3.3 Discussion

The results of this investigations showed that the young birds consumed significantly more from diet 3 (8.0% fat) compared with diet 1 (4.6% fat) and diet 2 (6.0% fat) during the first 6 days. However, birds' preferences changed during the next six days of the experiment: the birds consumed more from 4.6% and 6.0% fat diets (but not significant) than from the 8.0% fat diet. This is a clear indication that the birds preferred a high fat diet during the first 6 days of their lives, which may be linked to their utilization of stored yolk fats in their gut and their preference for high fat during the first few days after hatching (Appleby *et al.*, 2004). The lack of significant differences in consumption from the three diets during the second week of their growth development may reflect preferences for micronutrients other than fat.

Daily feed intake was influenced by the fat percentage content of the diet. Feed intake of diet 3 (8.0% fat) during the last 6 days was greater, but not significantly, so, than during the first 6 days, being 17g against 14g. However, feed intake of diet 1 (4.6% fat) was greater on the last 6 days than on the first 6 days, being 18g against 4g. Feed intake of diet 1 was approximately quadruple during the final 6 days that of the first 6 days (18g and 4g respectively). Chicks' choice of diet 2 also changed. During the first 6 days they averaged 2g intake; during the next 6 days they averaged 15g—nearly an 8-fold increase.

The result shows the broiler chicks can choose a diet that is more palatable in terms of percentage fat if they are offered a range of diets, and supports the idea that they choose a diet that provides them with all optimal nutrients levels (Hughes, 1984).

The results suggest that chicks can choose between the three diets used in the experiment. This may be due to a definite cognitive decision or an automatic response to the metabolic gains recognised by the their body, from eating the higher percentage feed which may be linked to the physical experience—palatability, texture, taste, smell, and so on—of the feeds. The results may also be linked to choices made by the broiler chicks when they are first introduced to the diets, which in itself may be linked to peer group dynamics.

Overall, the more active behavioural responses were higher for the younger chicks than for the older, except aggression, wing/body stretching and body grooming. It is concluded that the chicks were generally more active in the first days of their life. Behaviour has been shown to be strongly age dependent (Bokkers and Koene, 2003).

Not withstanding the early consequences of diet selection and dietary fat content, a further potentially stressful and important consideration in obtaining the best developmental performance from fowl is the nature and timing of dietary changes. Since optimal dietary composition changes throughout the life of the birds, dietary composition and characteristics must naturally change. When and what these changes should be is the focus on the next experiment (Chapter.4)

Chapter 4: The Effect of Gradual and Sudden Changes of Diet on Broiler Performance

4.1 Introduction

The literature suggests the diets of farmed birds change throughout their lives. Yet a sudden change of diet may have marked effects upon feed consumption and behaviour of broiler chicks (Picard, 1999; Hubber, 1997). Previous studies have showed that sudden change of diet affects feed intake, body weight and behaviour. For example, Picard (1999) observed that animals generally refuse to accept new type of food items, as well as diets with a new formulation, for a certain period of time. Sometimes animals will consume new diets, but, if so, usually at lower amounts. Rejection of feeding or lower intake changes behaviour in birds (Picard, 1999). When birds accept only lower amounts of the new diet, their performance may also be impaired because of increased pecking of the litter and their own faeces, which may cause disease (Picard, 1999). Hubber (1997) reported that abnormal bird behaviour—such as eating the own waste—can lead to the birds contracting disease and to feather loss. Savory *et al.* (1996) reported that abnormal behaviour in broiler chicks could happen as a result of hunger, malnutrition, stress, and frustration. It may be noted that acceptance or rejection of food depends on the perception of birds in relation to the diets offered; Picard *et al.* (2000) suggested that chicks have the ability to distinguish between food pellets that differed even minutely in physical shape.

Birds do not accept new feed immediately, so a gradual change in feed is desirable in order to make it acceptable. Neophobia (fear of the new) may be overcome by allowing animals to experience changing conditions in a gradual manner, perhaps by allowing animals to eat a new food alongside the familiar one, or by the addition of familiar flavours (Launchbaugh *et al.*, 1997).

The purpose of this study was to investigate the effect of gradual and sudden changes in physical form of two diets containing two different fat levels (4.6% and 8.0%) on feed intake, body weight, feed conversion ratio, dressing percentage, carcass composition, body components, and behaviour recorders (feeding, drinking, pecking, scratching and aggression) among young chicks.

4.2 Experiment 2

The hypothesis to be tested was that the groups of chicks eat more and grow faster in the case of gradual change of diet containing 4.6% and 8.0% fat than do chicks groups where changes of diet are made abruptly.

4.2.1 Materials and Methods

4.2.1.1 Animals and feeds

Sixty, 1-day old male broiler chicks (Aviagen hybred) were obtained from Grampian Country Food Ltd., Glan Dwr Poultry Unit, Anglesey (Wales) and were housed in pens throughout the 34 days of the experiment. Two starter types (crumbs and pellet) different in fat level (4.6 and 8.0% Soya oil), together with grower and finisher diets were used (see Appendix 1).

4.2.1.2 Procedure

Day-old chicks were weighed upon arrival and randomly distributed into 6 pens with 10 chicks per group. As mentioned, each chick in each group received a distinct colour mark to allow it to be distinguished. The length and width of the six pens were 145×109, 145 ×108,145×109, 145×111, 145×96, and 145×114cm respectively. Pens were provided with feed troughs and drinkers. See Plate 4.1.

Plate 4. 1. Pens with feed troughs and drinkers.

Fresh and clean water was available at all times from mini drinkers placed on the floor. The entire area of the floor was covered with wood shavings as litter. The experiment was carried out in an environmentally controlled pen.

Table 4.1 shows the maximum and minimum temperature and humidity of the room. The room was automatically ventilated, and checked regularly to ensure that ventilation was maintained within standards. A 24h/day lighting system was adopted during the first week followed by 23h light:1h dark regime in the second week as per commercial broiler production systems.

Table 4. 1. Temperature and humidity of experimental room.

Day	Temperature º C		Humidity %	
	Max.	Min.	Max.	Min.
1	30.8	27.7	27	23
2	30.9	28.1	27	23
3	28.5	26.4	29	25
4	28.7	26.5	29	25
5	28.7	27.4	33	25
6	28.7	27.3	36	25
7	27.5	27.3	35	30
8	27.5	27.2	35	29
9	27.5	25.7	35	28
10	26.8	26.5	31	26
11	26.8	25.8	39	31
12	26.7	25.3	41	24
13	25.7	25.3	29	24
14	25.8	24.3	34	28
15	24.5	24.2	42	34
16	24.7	24.3	46	41
17	24.2	23.8	46	35
18	23.9	22.2	36	31
19	22.6	22.2	32	30
20	22.7	22.2	42	30
21	22.7	21.9	53	42
22	22.3	21.3	50	46
23	21.5	21.0	50	44
24	21.6	21.1	49	44
25	21.0	20.5	54	45
26	21.0	20,1	52	40
27	20.5	20.0	41	36
28	20.5	19.9	41	35
29	20.5	20.3	42	40
30	20.4	20.0	44	40
31	20.5	19.8	44	40
32	20.5	19.9	47	37
33	20.6	20.1	53	47
34	20.8	20.3	56	43
35	20.9	20.2	56	46

4.2.1.3 Treatments

There were two main treatments (T1 and T2). The first, T1, pertained to a low fat diet (4.6%); the second, T2, to a high fat diet (8.0%). Each of these main treatments was divided into three sub-treatments. The first was sudden change (SC); the second was gradual change (GC); the third was late sudden change (LSC).

The experiment lasted 34 days. The schedule of these days, and of the manner of each treatment and sub-treatment changed, is provided in Box 4.1. See Appendix 1 for precise details of the composition of the diets used in this experiment.

In the rearing period the birds were fed a starter, grower, and finisher ration as described in Box 4.1. The birds were moved around the pens every day in the first week and then once every week to avoid any light or position effects.

Box 4. 1. Treatments: feeding procedure; experiment 2.

	Treatment 1(4.6% diet fat)			Treatment 2 (8.0% diet fat)		
Day	T1(SC)	T1(GC)	T1(LSC)	T2(SC)	T2(GC)	T2(LSC)
1–9	S crumb	S crumb	S crumb	S crumb	S crumb	S crumb
10	S pellet	75% S crumb + 25% S pellet	S crumb	S pellet	75% S crumb + 25% S pellet	S crumb
11	S pellet	50% S crumb + 50% S pellet	S crumb	S pellet	50% S crumb + 50% S pellet	S crumb
12	S pellet	25% S crumb + 75% S pellet	S crumb	S pellet	25% S crumb + 75% S pellet	S crumb
13–16	S pellet	S pellet	S pellet	S pellet	S pellet	S pellet
17	Grower	75% S pellet + 25% Grower	S pellet	Grower	75% S pellet + 25% Grower	S pellet
18	Grower	50% S pellet + 50% Grower	S pellet	Grower	50% S pellet + 50% Grower	S pellet
19	Grower	25% S pellet + 75% Grower	S pellet	Grower	25% S pellet + 75% Grower	S pellet
20–27	Grower	Grower	Grower	Grower	Grower	Grower
28	Finisher	75% Grower + 25% Finisher	Grower	Finisher	75% Grower + 25% Finisher	Grower
29	Finisher	50% Grower + 50% Finisher	Grower	Finisher	50% Grower + 50% Finisher	Grower
30	Finisher	25% Grower + 75% Finisher	Grower	Finisher	25% Grower + 75% Finisher	Grower
31–34	Finisher	Finisher	Finisher	Finisher	Finisher	Finisher

SC: Sudden Change; GC: Gradual Change; LSC: Late Sudden Change; S: Starter

4.2.1.4 Measurements

4.2.1.4.1 Feed intake

Feed intake was recorded every morning before the birds were fed.

4.2.1.4.2 Body weight

Chicks were weighed individually at 1, 3, 5, 7, 9, 11, 13, 14, 21, 28 and 35 days of age.

4.2.1.4.3 Feed conversion

It was not possible to calculate feed conversion efficiency ratios for individual birds as the birds were not housed individually; however, feed conversion efficiency ratios were calculated by the quantity of combined feed intake of each replicate (g) divided by average grams weight (g) gain of each replicate within the experiment period.

4.2.1.4.4 Body composition

At the end of the experiment, 4 birds in each treatment were selected randomly and slaughtered, cleaned, and halved. See Plate 4.2.

Plate 4. 2. Birds at end of experiment 2 prior to slaughter.

As much of the meat as possible, inclusive of skin, was removed from the bone of the left carcass half; flesh, skin and bone were weighed. The tissues were then cut into small pieces, homogenised in a food blender, and labelled. Samples of known weight were dried in a hot-air oven at 85° C for 4 days. The dried samples were ground in a milling machine for dry matter, moisture, fat, and protein content analysis.

4.2.1.4.4.1 Dry matter

Equation 4.1 shows the percentage of dry matter.

% dry matter = weight of dry sample x 100/weight of sample used   Equation 4.1

4.2.1.4.4.2 Moisture

Equation 4.2 shows the percentage of moisture.

% moisture = 100 –% dry matter Equation 4.2

4.2.1.4.4.3 Fat content

Fat content was determined according to procedures of Prayitno (1994), with some modification. The Soxtec 2050 auto fat extraction system (Appendix3) consists of an Extraction Unit, a Control Unit and a Drive Unit. One gram of each dried sample was placed into a thimble and inserted into the extraction unit. Solvent (80ml) was added to the extraction cups in a closed system. The cups were heated by the electric heating plate (137° C). The 4-steps extraction consisted of boiling (rapid solubilisation in boiling solvent), rinsing (efficient removal of remaining soluble matter), solvent recovery (easy collection of distilled solvent for re-use), and pre-drying (lifting of cups ensure of no oxidation of fat) for 2h; then the extraction aluminium cups containing residual fat (crude fat) were dried in an oven at 85–100° C for approximately 20 minutes, and allowed to cool; they were then weighed.

Equation 4.3 shows the percentage of crude fat.

% crude fat = (E3 –E2) x 100/E1 Equation 4.3

Where:

E1: weight of sample used
E2: weight of empty cup
E3: weight of the cup + crude fat

4.2.1.4.4.4 Protein content

Protein content was determined according to procedures of Halliday, (1985), with some modification. The Kjeldahl method of Nitrogen determination was used. It is a two stage process: first, acid digestion; second, titration.

Box 4.2 shows the reagents and procedure involved in acid digestion.

Box 4. 2. Reagents and procedures in acid digestion

Reagents:	Sulphuric acid (98%w/v)
	Kjeltabs 3.5g K_2So_4
	$CuSO_4$ $5H_2O$ 0.105g
	TiO_2 0.105g.
Procedure:	Transfer ~ 0.200 grams of milled dried sample into a micro-digestion tube.
	Add one of Kjeltab catalyst tablet. Place tube in a 40 tube rack.
	Duplicate each sample by the two steps above. Repeat until twenty-four samples have been weighed.
	Add 10ml of sulphuric acid to each tube.
	Insert the rack of 40 tubes into preheated (450° C) heating block contained within the fume cupboard. Digestion is complete when the acid mixture turns to the characteristic green colour (30 min).
	Remove the rack and allow to cool in fume cupboard.

Box 4.3 Reagents and procedure involved in titration.

Box 4. 3. Reagents and procedures in titration. Note: A Kjeltec 2300 auto analyzer unit (see Appendix 3) was used for the titration.

Reagents:	Sodium hydroxide (NaOH) 35–40%
	Boric acid 1% with bromocresol green/ methyl red indicator (100g to boric acid in 101 distilled water
	100 ml bromocreol green (100mg in 100ml methanol)
	70ml methyl red 9100mg in 100ml methanol)
	5ml sodium hydroxide 1m (4%) to give a positive blank
	Hydrochloric acid (HCl) 0.5m
Procedure:	Titrate each of three 20 ml of distilled water (blanks) prior to running a batch of samples. The blank value can be entered as a constant and the results adjusted accordingly.
	Insert one tube into the auto analyser. The ammonia produced from the breakdown of nitrogenous components (except No_3 + No_2) during the acid digestion stage is released by an automated addition of 25ml of Sodium hydroxide and a constant passage of steam through the resulting mixture. The ammonia is distilled and collected in the receiver solution.
	The result is calculated from the amount of titrant (HCl) required to reach the required end point of the receiver solution (rose) as detected by a photoelectric cell. An inbuilt calculator displays the result as nitrogen (%) or crude protein (%) automatically.

4.2.1.4.5 Behavioural recording

The behaviour of chicks was recorded for 6h daily (9.00–11.00 am), (12:00–14:00 pm) and (15:00–17:00 pm). The behaviours were observed and the incidence recorded for the following behavioural responses: feeding (standing and sitting) and drinking (standing and sitting). The behaviours were recorded manually (see Table 4.2). The behaviours were recorded every 5min during the hours in question, thus they were recoded for 60min per treatment per day.

Table 4. 2. Behavioural record chart 2.

Hour	T 1 (4.6% fat)												T 2 (8.0% fat)											
	T 1 SC				T1 GC				T1 LSC				T2 SC				T2GC				T2LSC			
	Fst	Fsi	Dst	Dsi	Fst	Fsi	Dst	Dsi	Fst	Fsi	Dst	Dsi	Fst	Fsi	Dst	Dsi	Fst	Fsi	Dst	Dsi	Fst	Fsi	Dst	Dsi
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13:00																								
13:30																								
15:00																								
15:30																								
16:00																								
16:30																								

Fst: Feeding Standing; Fsi: Feeding Sitting; Dst: Drinking Standing; Dsi: Drinking Sitting

4.2.1.5 Statistical analysis

Treatment effects of all variables were determined by a series of ANOVAs, in an analogous manner to that described for experiment 1, save that the data were not transformed (there was no need) and a between measures design was used. The dependent variables were feed intake, body weight, weight gain,, feed conversion ratio, carcass composition, weight of body components, and feeding and drinking behaviour The independent variables were treatment (T1 and T2: between measures) and sub-treatment (SC, GC, and LSC; between measures).

4.2.2 Results

4.2.2.1 The performance of broiler chickens

Statistical analysis of feed intake, body weight, weight gain, and feed conversion ratio showed no significant differences between treatments or between sub-treatments (Table 4.3). The rank order of groups in relation to total feed consumed was as shown in Box 4.4.

Table 4. 3. Mean feed intake, body weight, weight gain, and feed conversion ratio of male broilers.

Parameters	T1			T2			SE
	SC	GC	LTC	SC	GC	LSC	
Feed intake (g/bird/week)	734	737	724	705	736	722	± 223
Body weight(g/bird/week)	667	664	668	667	670	667	± 118
Weight gain (g/bird/week)	498	496	499	479	498	497	± 118
Feed conversion ratio(g/g)	1.3	1.3	1.3	1.3	1.3	1.3	± 0.14

($p < .05$); n=6

Box 4. 4. Rank order of groups.

Rank order	Feed intake
T1 SC	3688g/bird
T2 LSC	3678g/bird
T1 GC	3672g/bird
T1 LSC	3624g/bird
T2 GC	3608g/bird
T2 SC	3524g/bird

The figure reveals there was a tendency for feeding to become more erratic in the fifth week of the study. However, there were no significant interaction effects.

The results showed that different feed introduction regimes (sub-treatments) and diets (treatments) did not have any effect on carcass composition or weight of body components of the broiler chickens (Table 4.4).

Table 4. 4. Carcass composition and mean weight of body components.

Parameters	T1 (4.6% Fat)			T2 (8.0% Fat)			SE
	SC	GC	LSC	SC	GC	LSC	
	Carcass Composition (%)						
Dry matter	34	34	32	33	32	32	± 0.6
Moisture	66	66	68	67	68	68	± 0.6
Fat	42	40	40	41	39	37	± 1.9
Protein	54	53	56	51	54	58	± 2.2
	Body Components (g/bird)						
Left half	891	885	851	889	901	759	± 38.3
Flesh	612	591	572	599	610	522	± 27.0
Skin	104	101	80	108	102	93	± 8.60
Bone	171	190	188	171	179	133	± 13.0
Dressing Percentage	72	73	73	72	72	73	± 1.40

($p < .05$)

4.2.2 2 The behaviour of broiler chickens

Statistical analysis of the feeding (standing and sitting) and drinking (standing and sitting) responses showed no significant differences recorded between any of the 2 treatments, and no differences between any of the 3 sub-treatments (Table 4.5).

Table 4. 5. Mean of feeding, drinking, pecking, scratching and aggression behaviours during the 35 day experiment.

Parameters	T1			T2			SE
	SC	GC	LSC	SC	GC	LSC	
Feeding standing (no/b/h)	27	24	26	26	25	25	± 1.1
Feeding sitting (no/b/h)	0.4	0.6	0.5	0.2	0.3	0.4	± 0.1
Drinking standing(no/b/h)	22	25	23	25	21	23	± 0.8
Drinking sitting(no/b/h)	0.4	0.1	0.1	0.1	0.2	0.1	± 0.7

($p < .05$);no: number; b:bird; h: hour

4.2.3 Discussion

The purpose of this experiment was to investigate the effect of a sudden, gradual and late sudden change of two diets differing in fat content (4.6 and 8.0% fat) on feed intake, body weight, feed conversion ratio, carcass composition, weight of body components and feeding and drinking behaviour. There were no significant differences in all the parameters between two diets or between birds introduced to feeds

Feed intake of the two diets was similar throughout the experiment period. This result is different from that of Morris (1968), who found that laying hens overconsumed energy when fed high-energy diets, and the degree of overconsumption was greatest for strains with characteristically high-energy intakes. In addition, Fisher and Wilson (1974) showed that changes in feed intake were not inversely proportional to changes in dietary energy level, especially when broilers were fed moderate to high energy diets. Added high fat (8.0%) to the diet could be a beneficial procedure to reduce feed intake in order to obtain optimal body weight at market age. In particular, in those areas of the world where high-energy grains and feed-grade fats are relatively inexpensive, high-energy diets are often the most economical (NRC, 1994).

The mean intakes of sub-treatment gradual change in feed (GC) were higher than other sub-treatments (SC and LSC) (737g/bird and 736g/bird, respectively), but this difference was not significant; this suggests either that the birds could not recognize a difference among the feeds or that they showed no preference under the conditions.

Finally, it can be noted that the neither the SC nor the LSC sub-treatments, of either T1 or T2 treatments showed any statistical difference from either of the GC sub-treatments. At a commercial level, this may be important. Poultry producers perhaps need not worry about sudden changes in their birds' diets, within reason.

4.3 Experiment 3

The purpose of this study was to investigate the effect of a gradual and sudden change of two diets containing two different fat level (4.6% and 8.0% fat), and a third free-choice diet (containing both 4.6% + 8.0% fat) on feed intake, body weight, feed conversion ratio, dressing percentage, carcass composition, body components, and behaviour observed (feeding, drinking, pecking, scratching, and aggression) among groups of young chicks.

4.3.1 Materials and Methods

Materials and methods were as described for experiment 2, except that different behaviours were recorded. The behaviours recorded comprised.1) feeding, 2) drinking, 3) pecking, 4) scratching, and 5) aggression.

4.3.1.1 Treatment

Three treatments were used in this experiment: T1, T2, and T3. T1 feed contained 4.6% fat, T2 feed contained 8.0% fat and T3 birds were presented with both 4.6% and 8.0% diets for the first 5 days, and from then on their feeding regime followed that of birds in T1. Within each treatment, there were two sub-treatments: new feeds were introduced in two ways: gradual change (GC) of diet and sudden change (SC) of diet

The schedule of these days, and the manner of each treatment and sub-treatment changed, is provided in Box 4.5. In the rearing period the birds were fed a starter, grower, and finisher ration as described in Box 4.5.

Box 4. 5. Treatments: feeding procedure; experiment 3.

	Treatment 1 (4.6% Fat)		Treatment 2 (8.0% Fat)		Treatment 3 (4.6 + 8.0% Fat) first 5days and then (4.6% Fat)	
Day	T1 (GC)	T1 (SC)	T2 (GC)	T2 (SC)	T3 (GC)	T3 (SC)
1–5	S crumb	S crumb	S crumb	S crumb	S crumb(4.6+ 8.0% fat)	S crumb
6–9	S crumb	S crumb	S crumb	S crumb	S crumb(4.6% fat)	S crumb
10	75% S crumb + 25% S pellet	S pellet	75% S crumb + 25% S pellet	S pellet	75% S crumb + 25% S pellet	S pellet
11	50% S crumb + 50% S pellet	S pellet	50% S crumb + 50% S pellet	S pellet	50% S crumb + 50% S pellet	S pellet
12	25% S crumb + 75% S pellet	S pellet	25% S crumb + 75% S pellet	S pellet	25% S crumb + 75% S pellet	S pellet
13–16	S pellet	S pellet	S pellet	S pellet	S pellet	S pellet
17	75% S pellet + 25% Grower	Grower	75% S pellet + 25% Grower	Grower	75% S pellet + 25% Grower	Grower
18	50% S pellet + 50% Grower	Grower	50% S pellet + 50% Grower	Grower	50% S pellet + 50% Grower	Grower
19	25% S pellet + 75% Grower	Grower	25% S pellet + 75% Grower	Grower	25% S pellet + 75% Grower	Grower
20–27	Grower	Grower	Grower	Grower	Grower	Grower
28	75% S Grower + 25% Finisher	Finisher	75% S Grower + 25% Finisher	Finisher	75% S Grower + 25% Finisher	Finisher
29	50% S Grower + 50% Finisher	Finisher	50% S Grower + 50% Finisher	Finisher	50% S Grower + 50% Finisher	Finisher
30	25% S Grower + 75% Finisher	Finisher	25% S Grower + 75% Finisher	Finisher	25% S Grower + 75% Finisher	Finisher
31–35	Finisher	Finisher	Finisher	Finisher	Finisher	Finisher

GC: Gradual change of diet; SC: Sudden change of diet; S: Starter

4.3.1.2 Statistical analysis

Treatment effects of all variables were determined by a series of ANOVAs, in an analogous manner to that described for experiment 2. The dependent variables were as described in Section 4.3 (feed intake, body weight, weight gain, etc.). The independent variables were treatment (3 types: T1, T2, and T3, corresponding to low, high, and both; between measures) and sub-treatment (2: GC and SC; between measures).

There were two missing values; one was in the case of treatment T2 GC during experimental phase when one bird died out of ten on the 26th day of the experiment. Consequently, data were collected for the remaining nine birds for the rest of the period (10 days). Missing data in this case were on the following parameters: feed intake, body weight, body gain, and feed conversion ratio and behavioural Observations. The other missing values (T3 GC) were due to the loss of a carcass from the slaughterhouse. In this case the missing values were on body composition and dressing percentage.

4.3.2 Results

4.3.2.1 The performance of broiler chickens

Statistical analysis of feed intake throughout the experiment showed no differences between T1 (GC and SC), T2 GC, and T3 (GC and SC). However, a significant differences ($p < .05$) between T2SC and T1 (GC and SC) and T3 (GC and SC). Statistical analysis of body weight and weight gain results throughout the experiment showed differences between T1 SC, T3 SC and T2 SC. However, no differences between T1 (GC and SC), T2 GC, and T3 (GC and SC).

No differences between any of the 3 treatments and method of feed introduction groups in terms of feed conversion ratio (Table 4.6).

Table 4. 6. Mean feed intake, body weight, weight gain and feed conversion ratio of male broilers.

Parameters	T1		T2		T3		SE
	GC	SC	GC	SC	GC	SC	
Feed intake (g/bird/week)	788[a]	806[a]	770 [ab]	723[b]	776[a]	815 [a]	± 10.8
Body weight(g/bird/week)	473[ab]	476[a]	462 [ab]	437[b]	464 [ab]	483 [a]	± 9.9
Weight gain (g/bird/week)	465[ab]	467[a]	454 [ab]	429[b]	455 [ab]	474 [a]	± 8.5
Feed conversion ratio(g/g)	1.6	1.6	1.6	1.6	1.6	1.6	± 0.02

[a,b] Mean values not sharing a common superscript letter same row are significantly different ($p < .05$)

A significant differences ($p < .05$) occurred between diet 1 and diet 2 in terms of mean intake (diet 1: 48g; diet 2: 137g) when feed was offered in a free-choice regime in the first 5 days (Table 4.7).

Table 4. 7. Mean feed intake of T3 over the first 5 days.

Diet	Total Mean Intake (g)
Diet1 (4.6% fat)	48 [a]
Diet2 (8.0% fat)	137 [b]
SE	± 1.4

[a,b] Mean values not sharing a common superscript letter are significantly different ($p < .05$)

The results showed that different dietary fat levels or feed introduction methods did not have any effect on carcass composition and weight of body components of the broiler chickens except in terms of protein levels (Table 4.8).

Table 4. 8. Carcass composition and mean weight of body components.

Parameters	T1		T2		T3		SE
	GC	SC	GC	SC	GC	SC	
	Carcass Composition (%)						
Dry matter	37	32	32	36	37	33	± 1.03
Moisture	63	68	68	64	63	67	± 1.03
Fat	39	32	37	35	37	33	± 1.99
Protein	55	63	61	55	55	58	± 2.13
	Body components (g/bird)						
Left half	912	935	929	935	947	886	± 46.3
Flesh	607	615	603	625	639	588	± 30.8
Skin	85	84	80	84	89	79	± 4.89
Bone	171	189	183	189	177	185	± 11.7
Dressing Percentage	71	72	71	72	72	71	± 0.40

($p < .05$)

4.3.2.2 The behaviour of broiler chickens

Feeding and drinking times were not affected by any of the treatment conditions, but the incidence of pecking was highest for broilers in the T2 SC and lowest for broilers in T1 SC and.T3 SC. Statistical analysis of the scratching results showed significant differences ($p < .05$) between the T1 GC and T2 SC groups; the mean of T1 GC was 0.9 compared to 2.1 for T2 SC. However, no significant difference between the T1 GC, T1 SC, T2 GC, T3 GC, and T3 SC groups. Aggression results showed significant differences ($p < .05$) between the T1 GC and T2 SC groups; the mean of T1 GC was 2.6 compared to 1.0 for T2 SC. However, no differences between the T1 GC, T1 SC, T2 GC, T3 GC, and T 3 SC groups (Table 4.9 and Figure 4.1).

Table 4. 9. Mean of feeding, drinking, pecking, scratching and aggression behaviours during the 35 day experiment.

Parameters	T1		T2		T3		SE
	GC	SC	GC	SC	GC	SC	
Feeding (no/b/h)	19	21	20	22	21	20	± 1.0
Drinking(no/b/h)	19	21	20	19	18	20	± 1.0
Pecking (no/b/h)	17 [a]	16 [a]	20[ab]	23 [b]	19 [ab]	17 [a]	± 1.2
Scratching (no/b/h)	0.9 [a]	1.1 [ab]	1.9 [ab]	2.1 [b]	1.7 [ab]	1.6 [ab]	± 0.3
Aggression (no/b/h)	2.6 [a]	2.1 [ab]	1.3 [ab]	1.0 [b]	1.4 [ab]	1.3 [ab]	± 0.3

[a,b] Mean values not sharing a common superscript letter same row are significantly different ($p < .05$), no: number; b:bird; h: hour

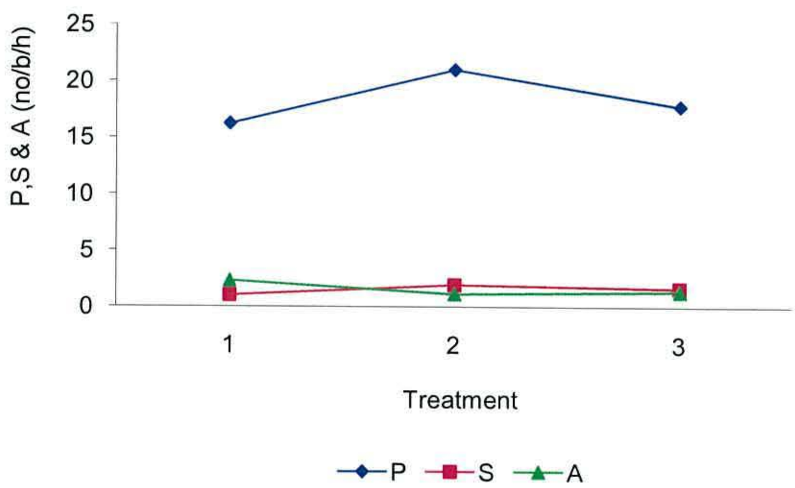

Figure 4. 1. Pecking (P), scratching(S) and aggression (A) behaviours during the whole period (5weeks)

4.3.3 Discussion

The purpose of this experiment was same as experiment 2; to investigate the effect of a gradual and sudden change of two diets (4.6 and 8.0% fat) on feed intake, body weight, feed conversion ratio, dressing percentage, carcass composition, body components and behaviour observed (feeding, drinking, pecking, scratching and aggression). However, in addition this experiment included a diet free-choice feeding period during the first 5 days of the birds' development.

Feed intake of T1 and T3 was higher than feed intake of T2. This difference in intake may be due to the fat level in the diet. This result is again in disagreement with Morris (1968) who reported hens overconsuming energy when fed with high-energy diets. As noted, Fisher and Wilson (1974) also showed that feed intake did not decline with increasing energy content of the diet, suggesting that chickens to do not appear to maintain energy consumption levels when given free-choice, but are rather energy intake maximizers.

The result of this experiment have shown that body weight of birds in the three treatments was not significantly affected except in the case of T2 SC birds, which may be attributed to sudden change of diet. The results are similar to those of Fontana *et al.* (1992), who found no significant reduction in weight of chickens when feed was changed. Significant differences between three treatments in terms of pecking, scratching, and aggression were also found.

One interesting aspect is that birds that experienced a sudden change in feed were leaner than birds experiencing a gradual change, although these differences were not statistically significant (body fat levels 32, 35 and 33% versus 39, 37 and 37% respectively). Feed intake, body weight, and weight gain of sudden change groups in T1 and T3 were higher than gradual change groups in T1 and T3. T2 birds exhibited the lowest levels. The sudden change of diet had a negative effect on T2 birds (8.0% fat) in one single case. The reason for this is unknown. On the other hand, gradual change feeding has a positive effect on T2 only. It may be concluded that gradual change feeding offers no advantage in terms of broiler performance. Again, as in the case for commercial poultry producers, gradual change feeding is arguably a more complicated and costly procedure.

Pecking and scratching behaviours during the 35 day experiment in T1 GC decreased and in T2 SC increased. These findings corroborate the result of pervious studies that reveals that a change in meal size leads to pecking at non-food objects (Savory and Mann, 1999). Aggression in T1 GC increased and in T2 SC it decreased. This might be due to the difference of fat level in the diet or the way of introducing the feed. Sudden changes reduce aggressive behaviours that are considered to be indicative of stress, but, in the present study, sudden change did not affect the body weight of broilers. Frustration associated with feeding has been shown to increase aggression of laying strain males towards females (Duncan and Wood-Gush, 1971).

Regardless of the effects of the speed of change in the diets provided to farmed birds, the increasing public awareness and demand for more natural (organic or humane) farming practices, in conjunction with studies that suggest that birds offered selection can optimally choose their own requirements for maximal performance, has focused attention on free selection. In younger birds free diet selection has had little attention. Consequently, the next chapter investigates principally the role of free-choice in farmed fowl performance development.

Chapter 5: The Effect of Free Choice Feeding on High (8.0%) and Low (4.6%) Fat Diets by Male Broilers on Diet Selection Preference

5.1 Introduction

Free choice dietary provision is a potential marketing boon for the industry if developmental performance can be maintained (or even improved). The green movement and awareness of consumers strongly hint at changing consumer preferences, not only about the quality and price of food but also the welfare of the animals. Providing free-choice seems more natural than fixed diets from the perspective of the consumers. But the question remains whether this is an economical option for the industry.

The most recent reports suggest that chickens, when given a choice between two foods, one containing more and another less of a nutrient than would be optimal for development, will within a few days, be selecting food mixtures that provides as more or less balanced diet (Fuller, 2004). Earlier studies by Hughes (1984) had also found that domestic birds could choose a diet that provides them with all essential nutrients as long as a sufficient range of foodstuffs were made available. It appears that the final selection is dependent on them sampling all potential food items. For example, domestic fowls that are deficient in a particular nutrient such as calcium or sodium show an increase in generalized searching behaviour, pecking at objects that they would not normally investigate (Wood-Gush and Kare, 1966; Hughes and Whitehead, 1979). After this initial sampling, the birds will then continue to consume those items that are most palatable and nutritious (Hogan, 1973).

Food selection can be very precise. As mentioned, preference tests have shown that the fowl has specific appetites for essential elements such as calcium (Mongin and Sauver, 1979), phosphorus (Holcombe *et al.*, 1976a), and zinc (Hughes and Dewar, 1971); for vitamins such as thiamine (Hughes and Wood-Gush, 1971a); and for protein (Holcombe *et al.*, 1976b). Also given a choice of pellets and wheat, turkey hens ate 46% as wheat whereas males chose only 38% (McDonald and Emmans, 1980). Although there was no significant effect on body weight, early lay free-choice fed pullets produced significantly fewer eggs. In addition, egg weights and hatchability were marginally lower for birds on free-choice feeding regimes.

Rose and Abbas (1993) observed that cockerels selected different varieties of wheat according to their nutritive value. This was correlated with the growth rate of broilers, which were given foods containing 70% wheat, providing a potentially useful method for evaluation of nutritive value of wheat.

It has been frequently documented that chicks rely heavily on yolk fat (Freeman, 1965; Broom, 1968 Rogers, 1989; Forbes 1995; Appleby *et al.*, 2004) during their first few days of their lives. However, most current standard commercial starter diets contain low fat percent (approximately 4.6%) and high protein (approximately 24%), in addition to all essential nutrients.

5.2 Experiment 4

Many different approaches may be taken to test diet selection during this early developmental period. For this experiment the link between fat consumption and diet selection during the first few days of a chick's life was investigated. A high-fat diet (HF) and a low-fat diet (LF) were offered in a free-choice regime to 3 day old chicks after the chicks were familiarised with the nutritional values of both the high-fat diet (HF) or a low-fat diet (LF) by feeding each in alternate 12h periods for 2 days to allow them to memorize any sensory properties of each diet. The objective was to see if they would consume more of the higher fat level (8.0%) diet during the first week of their lives thus showing very early developmental stage diet selection behaviour.

5.2.1 Materials and Methods

Materials and methods were as described for experiment 2, except that different behaviours were recorded. The behaviours recorded comprised.1) feeding, 2) drinking, 3) pecking, and 4) aggression.

5.2.1.1 Treatment

Chicks were first familiarised with the nutritional value of a high-fat diet (HF) (8.0%) or a low-fat diet (LF) (4.6%) by feeding each in alternate 12h periods for 2 days to allow them to associate the sensory properties of each diet (Shariatmadari and Forbes, 1993). Two treatments were used in this experiment: T1 (HF for the 1st 12h followed by LF for the 2nd 12h on the 1st day; HF for the 1st 12h followed by LF for the 2nd 12h on the 2nd day) and T2 (LF for the 1st 12h followed by HF for the 2nd 12h on the 1st day; LF for the 1st 12h followed by HF for the 2nd 12h on the 2nd day). Chicks were then offered a choice between HF and LF for 6 days after 2h fasting. (See Plate 5.1). In the remaining 27 days, the birds were fed a starter, grower, and finisher ration, as illustrated in Box 5.1.

Plate 5. 1. Feeders offering free-choice high fat and low fat starter crumbs diet.

Box 5. 1. Treatments: feeding procedure; experiment 4.

	Treatments	
Day	T1	T2
1–2	HF starter crumb diet (first 12h). LF (second12h) starter crumb diet	LF starter crumb diet (first 12h). HF (second12h) starter crumb diet
3	2h fast followed by HF and LF diet. Free-choice	2h fast followed by HF and LF diet. Free-choice
4–8	HF and LF starter crumb diet. Free-choice	HF and LF starter crumb diet. Free-choice
9–14	Starter pellet diet	Starter pellet diet
15–28	Grower diet	Grower diet
29–35	Finisher diet	Finisher diet

HF: high fat; LF: low fat

5.2.1.5 Statistical analysis

Treatment effects of all variables were determined by a series of ANOVAs, in an analogous manner to that described for experiment 3. The dependent variables were as described in Section 4.3 (feed intake, body weight, weight gain, etc.). The most important dependent variable as regards treatment was fat content (HF or LF). The independent variable was treatment (T1 and T2; between measures).

(ANOVA was used in this instance, as in similar instances in the present study, instead of *t*-tests purely for consistency of presentation—ANOVAs on two samples produce identical results to *t*-tests. See Field, 2000).

5.2.2 Results

5.2.2.1 The performance of broiler chickens

Statistical analysis of the weekly feed intake, body weight, weight gain and feed conversion ratio results showed no differences between the two treatments, Table 5.1.

Table 5. 1. Mean feed intake, body weight, weight gain and feed conversion ratio.

	Week				
Treatment	1	2	3	4	5
		Feed intake (g/bird/week)			
T1	180	477	777	1071	1366
T2	182	468	766	1077	1343
SE	± 5.8	± 9.3	± 16.8	± 23.7	± 70.3
		Body weight (g/bird/week)			
T1	223	597	1173	1886	2674
T2	217	580	1152	1850	2627
SE	± 4.8	± 15.3	± 27.6	± 41.8	± 63.6
		Weight gain (g/bird/week)			
T1	179	374	576	712	788
T2	172	363	572	699	777
SE	± 4.8	± 10.0	± 13.9	± 14.7	± 31.5
		Feed conversion ratio (g /g)			
T1	1.0	1.3	1.3	1.5	1.7
T2	1.1	1.3	1.3	1.5	1.7
SE	± 0.02	± 0.02	± 0.03	± 0.02	± 0.05

($p < .05$)

There were no significant differences recorded between the two treatments in terms of total feed intake, final body weight, weight gain and feed conversion ratio, Table 5.2.

Table 5. 2. Total feed intake, final body weight, weight gain and feed conversion ratio of male broilers during whole trial period (35 days).

Parameters	T1	T2	SE
Total feed intake (g/bird)	3870	3835	± 73.9
Final body weight (g/bird)	2586	2541	± 122.3
Final weight gain (g/bird)	2541	2496	± 122.3
Feed conversion ratio(g/g)	1.5	1.5	± 0.06

($p < .05$)

A summary of the results is presented in Table 5.3 and Figure 5.1. A significant difference ($p < .05$) was recorded between 4.6% fat standard commercial starter diet and 8.0% fat starter diet within both treatments (T1: 72 g/bird/d high fat versus 26 g/bird/d low fat and T2: 67 g/bird/d high fat versus 33 g/bird/d low fat)

Table 5. 3. Mean feed intake during the free-choice period (6 days).

Fat level in diet	T1 (g/bird/day)	T2 (g/bird/day)
HF	72 ^{a}	67 ^{a}
LF	26 ^{b}	33 ^{b}
SE		± 4.1

^{a,b} Mean values not sharing a common superscript letter are significantly different ($p < .05$)

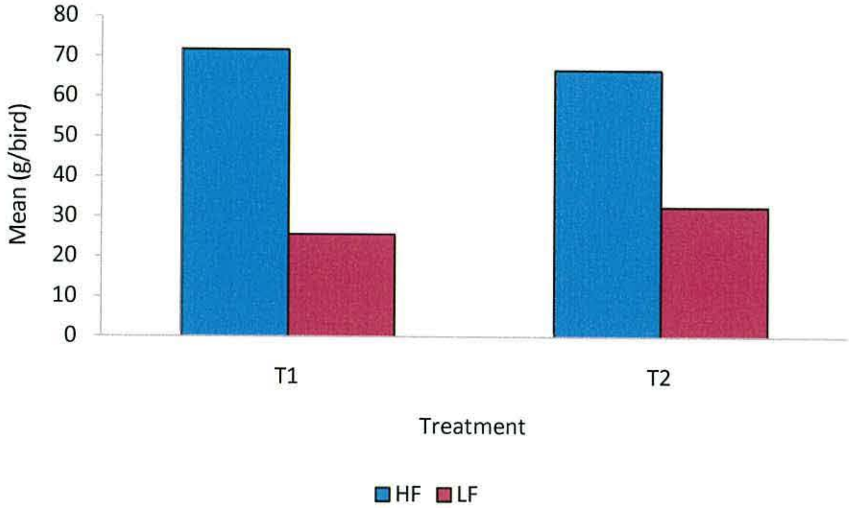

Figure 5. 1. Mean feed intake of high (HF) and low fat (LF) diets during the free-choice period (6 days) of two treatments.

The results showed that treatments did not have any effect on carcass composition and body components of the broiler chickens, Table 5.4.

Table 5. 4. Carcass composition and mean weight of body components.

Parameters	T1	T2	SE
	Carcass Composition (%)		
Dry matter	33	37	± 4.0
Moisture	67	63	± 4.0
Fat	35	40	± 4.1
Protein	53	48	± 6.9
	Body Components (g/bird)		
Left half	942	944	± 55.0
Flesh	604	595	± 80.0
Skin	83	86	± 12.1
Bone	203	212	± 39.0
Dressing percentage	71	71	± 2.00

($p < .05$)

5.2.2.2 The behaviour of broiler chickens

A summary of results for feeding, drinking, pecking, and aggression behaviours are presented in Table 5.5. Statistical analysis of the results showed no differences detected between the 2 treatments.

Table 5. 5. Mean of feeding, drinking, pecking, and aggression behaviours during the 35 day experiment.

Parameters	T1	T2	SE
Feeding(no/b/h)	24	23	± 0.9
Drinking(no/b/h)	21	20	± 0.7
Pecking (no/b/h))	16	19	± 0.8
Aggression (no/b/h)	1.0	1.3	± 0.2

($p < .05$); no: number; b: bird; h: hour

In terms of feeding behaviour there was no significant difference between high-fat diet T1 and high-fat diet T2 and no significant difference between low-fat diet T1, low-fat diet T2, but there was a significant difference ($p < .05$) between high-fat diet T1 and low-fat diet T1, where the mean was calculated at 20 no/b/h compared to 8 no/b/h respectively. There was no significant difference between high-fat diet T2 and low-fat diet T2. See Table 5.6.

Table 5. 6. Mean of feeding behaviour during free-choice period (6 days).

Fat level	T1	T2	SE
	(no/b/h)		
HF	20^{a}	15^{ac}	± 1.6
LF	8^{b}	11^{bc}	± 1.6

^{a,b} Mean values not sharing a common superscript letter are significantly different ($p < .05$); no: number; b:bird; h: hour

5.2.3 Discussion

The purpose of this experiment was to investigate whether the composition of the diet had an immediate effect on diet selection. The results of this experiment showed that feed intake, body weight, body weight gain, feed conversion ratio, dressing percentage, carcass composition, body components, and behavioural parameters (feeding, drinking, pecking and aggression) did not differ by the treatments. However, body weight was higher for all weeks for T1 chicks, though the difference was not significant. This is intriguing, given that the treatment groups differed only in the order they were given high fat and low fat diets (see Box 5.1). Future research might shed light on this issue.

There were significant differences ($p < .05$) attributable to fat supplemental in feed intake during the 6 days free-choice periods; broilers consumed 72g of HF T1 and 67g of HF T2 and 26g of LF T1 and 33g of LF T2. This is a clear indication that the birds preferred a high fat diet during the first 6 days of their lives, which may be linked to their similar observed consumption of their high fat yolk sac during the first few days after hatching (Freeman, 1965; Broom, 1968 Rogers, 1989; Forbes 1995; Appleby *et al.*2004). The result suggests that the broiler chicks can choose a diet that is more palatable in terms of percentage fat if they are offered a range of diets. This is consistent with the conclusion that birds choose a diet that provides them with all necessary nutrients (Hughes, 1984).

The results suggest that the chicks were making a choice between the two diets used in the experiment. This may be due to a definite cognitive decision or an autonomic response to the metabolic gains detected by the their body, from eating the higher percentage feed that may be linked to physical experience of the feeds –palatability, texture, taste, smell, etc.

Yet regardless of the performance of the younger stages of the birds, the critical question remains as to the overall performance metrics of birds grown to culling weights or stages. Simple statistical differences in early performance are no guarantee that birds fed under such regimes will provide an economical advantage in terms of development times, final weights, and so on. The subsequent experiment considered the longer term outcomes of diet selection on bird performance metrics in order to shed light on these issues.

Chapter 6: The Effect of High and Low Fat Diets on The Performance of Male Broiler Chickens Grown to 30 Days Old

6.1 Introduction

Selecting an appropriate level of dietary energy level is, according to Skinner *et al.* (1992), a critical decision in formulating poultry diets, as it may contribute to about 70% of the total cost of poultry diets. At the same time, energy level optimises carcass quality, growth, feed efficiency, and allows a more lucrative production regime.

The poultry industry has seen a noticeable growth in broiler production throughout the world; for example, over the last 40 years in the developing countries there have been outstanding augmentations in growth rate in commercial broiler chickens (Tabeidian *et al.*, 2005). This trend is not peculiar to poultry production. The world is now feeding more people than ever before and it is feeding them *better* than ever before: in the 1950s, about 30% of the world's population was starving; today, the figure is approaching 12% (Lomborg, 2001; and see Avery, 1995). As of 1999, calorie intake of people worldwide had risen 24% over 1961 levels, and that of people in the developing world 38% (Lomborg, 2001). This development is almost entirely due to improvements in agricultural technology and, particularly relevant to the present study, improvements in methods of animal husbandry (Avery, 1995). Also note that, as the world becomes richer, its people demand ever higher intake of meat. Voluntary vegetarians are very rare (Harris, 1986; Avery, 1995). World production of meat, as of 2000, had increased 122% from 1950 levels (Lomborg, 2001).

The trend towards even higher efficiency in poultry production requires high-energy diets to achieve the high performance levels in commercial broiler chicks, although the required level of energy that need to be contributed by conventional feed ingredients is still ambiguous (Saleh *et al.*, 2004a, 2004b). Fat is typically used in formulating high levels of energy in poultry diets, even though its amount in the abdominal cavity remains a problem with commercial broilers. Choct *et al.* (2000) state that modern broilers contain about 150–200g fat per kg body weight and over 85% of it is physiologically nonessential, while abdominal fat is removed by evisceration, as a result diminishing processing yield. Fat as energy is available either from plant sources such as soya oil, sunflower oil, or from animal sources such as tallow or fish oil. Yeh and Leveille (1971) point out that fat in the diet is significant for its role in digestive inhibition, which augments energy efficiency in diets. Conventionally, tallow is used as a source of fat in poultry diets, being used also with other saturated animal fats in later phases of feeding, because of restricted digestibility in young chicken (Leeson and Summers, 2001). Tallow contains about 42.5% saturated fatty acids, while unsaturated fatty acids form only 1%: all of them are in n-6 fatty acid form (Manila *et al.*, 1999).

This experiment aims to investigate whether broilers that eat a diet containing 2% more fat than recommended by the NRC in starter, grower, and finisher stages require fewer days to reach a specified target weight (2kg) in order to minimize capital costs of housing, equipment, and labour.

6.2 Experiment 5

6.2.1 Materials and Methods

Materials and methods were the same as for experiment 4.

6.2.1.1 Treatments

There were two treatment groups, T1 and T2. T1 chicks were a control group, and were fed the standard low fat diet as used in most poultry production. T2 chicks were fed a diet 2% higher in fat than that used in standard commercial poultry production. See Box 6.1. There were 60 birds in each treatment.

Box 6. 1. Treatment: feeding procedure; experiment 5.

	Treatments	
Diet	T1	T2
Starter crumb (fat %)	4.6	6.6
Starter pellet (fat %)	6.7	8.7
Grower (fat %)	7.7	9.7
Finisher (fat %)	9.1	11.1

T1: control groups

6.2.1.2 Statistical analysis

Treatment effects of all variables were determined by a series of ANOVAs, in an analogous manner to that described for experiment 4. The dependent variables were as described in Section 4.3 (feed intake, body weight, weight gain, etc.). The independent variable was treatment.

6.2.2 Results

6.2.2.1 The performance of broiler chickens

Statistical analysis of feed intake and body weight results showed no differences observed between the two treatments on days 7, 14, 21; however, there were significantly ($p < .05$) greater for T1 than T2 on days 28 and 30. There were no differences between the two treatments in terms of weight gain and feed conversion ratio (Table 6.1).

Table 6. 1. Mean feed intake, body weight, weight gain and feed conversion ratio.

	Day				
Treatment	7	14	21	28	30
		Feed intake (g/bird)			
T1	167	444	788	1155[a]	589 [a]
T2	163	421	742	1046 [b]	529 [b]
SE	± 9.2	± 22.8	± 44.3	± 65.4	± 40.1
		Body weight (g/bird)			
T1	217	588	1194	1967[a]	2334 [a]
T2	215	570	1135	1854 [b]	2213 [b]
SE	± 10.3	± 29.2	± 50.9	± 94.5	± 112.4
		Weight gain (g/bird)			
T1	174	371	606	773	367
T2	172	354	565	720	358
SE	± 10.4	± 21.4	± 26.8	± 51.1	± 47.1
		Feed conversion ratio (g /g)			
T1	1.0	1.2	1.3	1.5	1.6
T2	1.0	1.2	1.3	1.5	1.5
SE	± 0.04	± 0.03	± 0.05	± 0.09	± 0.12

($p < .05$)

Total feed intake, final body weight, weight gain and feed conversion ratio of male broilers during the whole study period (30 days) are presented in Table 6.2. A significant difference ($p < .05$) was recorded between T1 and T2 in terms of total feed intake where the mean of total feed intake T1 was 3143g compared to 2899g for total feed intake of T2 (Figure 6.1). This result was in agreement with those of Grobas *et al.* (1999a, 1999b), Sohail *et al.* (2003), Bryant *et al.* (2005), and Zou and Wu (2005), who reported that supplemental fat had a significant effect on feed intake. There were no other differences between the two treatments for the remaining measured parameters.

Table 6. 2. Total feed intake, final body weight, weight gain and feed conversion ratio of male broilers during whole period (30 days).

Parameters	T1	T2	SE
Total feed intake (g/bird)	3143 [a]	2899 [b]	± 188.3
Final body weight (g/bird))	2334	2213	± 122.6
Final weight gain(g/bird)	2290	2169	± 122.6
Feed conversion ratio (g/g)	1.5	1.3	± 0.07

[a,b] Mean values not sharing a common superscript letter are significantly different (*p* < .05)

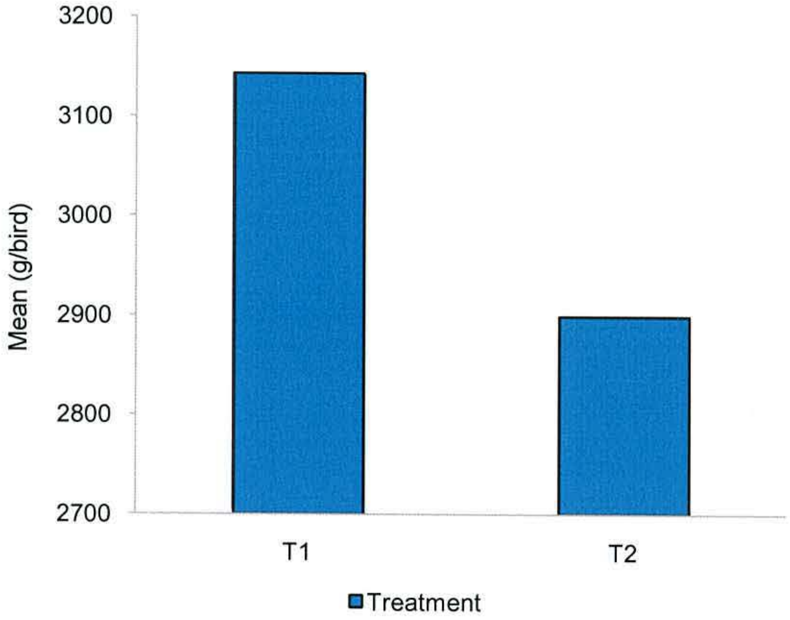

Figure 6. 1. Total feed intake by the end of the experiment (30 days) for both treatments.

The results showed that treatment had no significant effect on carcass composition or weight of body components of the broiler chickens (Table 6.3).

Table 6. 3. Carcass composition and mean weight of body components.

Parameters	T1	T2	SE
	Carcass Composition (%)		
Dry matter	32	33	± 2.6
Moisture	68	67	± 2.6
Fat	41	41	± 4.0
Protein	56	56	± 3.1
	Body Components (g/bird)		
Left half	752	759	± 70.4
Flesh	442	461	± 86.7
Skin	76	78	± 7.80
Bone	219	222	± 25.4
Dressing Percentage	72	73	± 1.40

($p < .05$)

6.2.2.2 The behaviour of broiler chickens

A summary of the results for feeding, drinking, pecking, and aggressive behaviours are presented in Table 6.4. Statistical analysis of the results showed no differences detected between the two treatments.

Table 6. 4. Mean of feeding, drinking, pecking, and aggression behaviours during 30 days experiment.

Parameters	T1	T2	SE
Feeding(no/b/h)	7	8	± 4.5
Drinking(no/b/h)	7	7	± 4.0
Pecking (no/b/h)	7	8	± 4.5
Aggression (no/b/h)	0.3	0.1	± 0.7

($p < .05$); no: number; b: bird; h: hour

6.2.3 Discussion

This study examined the effect of two different dietary fat levels on chick performance when supplied throughout all developmental stages (starter, grower, and finisher). Total feed intake of male broilers fed a high fat diet were significantly ($p < .05$) lower than intakes of broilers fed a low fat diet. This result is in agreement with that of Ali *et al.* (2001), who found that total feed intake of broilers fed a 10% soya oil diet were lower in comparison with that of broilers fed lower levels of soya oil. This finding is similar to the decreased feed intake with increasing energy density reported in previous studies in younger birds (Noy and Sklan, 2002) and older birds (Plavnik *et al.*, 1997). In general, decreasing feed intake is probably due to higher dietary energy density.

Feeding chicks two different levels of soya oil had no significant effect on body weight in 7–21-day-old chicks, but between ages 28–30 days, using a diet containing 2% more fat than recommended by NRC, significantly ($p < .05$) decreased body weight. There were no significant differences in weight gain, feed conversion ratio, carcass composition, body components, and feeding, drinking, pecking, and aggressive behaviours in chicks fed with different experimental diets. These results are in contrast with those of Farrell *et al.* (1976), Waldroup (1981), Jackson *et al.* (1982), Sohn and Han (1983a, 1983b), Bartov (1992), and Leeson *et al.* (1996), who all reported an increase in body weight gain and improved feed conversion ratios for birds provided with increasing levels of dietary energy.

The results of the present experiment suggest that feeding a diet containing 2% more fat than recommended by the NRC for 1–30-day-old chicks results in negative effects on body weight. Since high fat diets often cost much more than do low fat diets, it is clearly of little economical advantage to feed chicks under these conditions, especially since the feed represents about 65% of the total cost of production.

Fat content is only one consideration when looking at the optimal diet. For this reason it is also important to consider other dietary cues that the birds may use when selecting a diet under a free-choice situation. The next chapter explores the concept of feed colour in this respect.

Chapter 7: Male Broiler Chicks Feeding Preferences with Particular Respect to Birds Using Colour Cues

7.1 Introduction

A number of studies have shown that learning in relation to foraging in birds is often supported by specific properties associated with the food presented. These properties can include: taste, odour, texture, food form, position, colour of feeding troughs, and colour of the food. As the title of this chapter suggests, specific emphasis will be made to how birds use visual cues in relation to their feeding preferences and foraging behaviour.

It is well understood that visual cues are extremely important to very young chicks in relation to observed pecking preferences of various seeds. This was demonstrated by Rodgers (1967) by showing that seed preferences were unaffected by removal (through beak trimming) of the tactile proprioceptors in the tip of the beak of young birds. The vision of chickens is similar to humans in being chromatic (Lashley, 1916), although chickens have a greater sensitivity to the red portion of the spectrum and a decreased sensitivity to the blue (Walls, 1942). This range of chromatic vision in chickens means that they are well suited to utilizing visual discrimination when foraging and that they can differentiate colours across a broad spectrum range (Guhl, 1962; Gunter, 1964; Kilham *et al.*, 1968; Mallot, 1968; Taylor *et al.*, 1969).

It has often been noted that many birds' colour preferences change dependent on different stimuli. A number of experiments have highlighted that the use of colour as a stimulus may have utility in modifying food consumption. While the majority of experiments investigating poultry colour perception have revealed colour-based feeding preference in poultry, these studies are by no means consistent in determining a single conclusive pattern of food colour preferences. The reason for this is that colour preferences appear to be modified by many factors, including visual experiences gained by the birds.

The literature on visual cues reveals many behavioural phenomena in poultry. Hughes and Wood-Gush (1971a) indicated that, while both visual or taste cues allow birds to identify appropriate diets, birds making food choices tend to use visual cues more frequently, or to pay more heed to them. Interestingly, round and solid objects are pecked at more than angular and flat objects by newly-hatched chicks; this perhaps reflects the natural characteristics of nutritional seeds (Fantz, 1957). The predisposition of young chicks to peck at small, three-dimensional objects in the yellow to red range of the spectrum (Dawkins, 1971a) determines what seed types the chicks are more likely to peck at first. However, a number of subsequent factors will often determine whether chicks will continue to peck at the same type of seed or alternatively switch types. Food colour preference experiments demonstrate that chickens often employ colour in learning associations. Frequently when these associations are made generating behavioural shifts away from specifically coloured foods is frequently difficult (Capreta, 1961; Mackintosh, 1965; Dawkins, 1971b). Reports suggest that chickens prefer light-coloured feeds, in particular pink (Hess and Gogel, 1954), yet alternative preferences can be induced simply by prior exposure to different colour-food type associations. A study by Hurnik *et al.* (1970) suggested that those researchers who tested birds for the preference to blue, green, yellow, and red coloured feeds, reported that the most preferred colour was blue and the least preferred was red.

The colour preference of chickens are also not consistent across stimuli types, since it is often found that colour preferences shown for food stimuli are not the same for other types of stimuli. Yet the data on colour preferences does to some extent support the proposition that birds are predisposed to associate certain foraging related visual cues with sickness (Rozin and Kalat, 1971).

Since examination of birds shows that they usually have only a sparse number of taste-buds but excellent vision, it is not unreasonable to assume that taste learned associations would be subordinate to sight learned association in birds. Indeed this seems to be the case. Wilcoxon *et al.* (1971) showed that birds that became sick after drinking a mixture of blue-coloured and sour-tasting water would subsequently more frequently avoid blue rather than sour water when present singly. Nevertheless, evidence also suggests that there is a strong association between taste and substance that specifically affects digestion even in very visual bird species (Garcia *et al.*, 1974; Brett *et al.*, 1976). For example, hawks that possess millions of visual receptors yet relatively few taste receptors will still demonstrate a strong taste based aversion behaviour in relation to poisonous bait. However, the general conclusions are that colour is a strong cue for learned aversion (Martin *et al.*, 1977) and foraging preferences (Kutlu and Forbes, 1993). In addition, birds frequently use-vision based associations between food and internal physical changes (Martin *et al.*, 1977).

Finally on this issue, there is the vast literature on imprinting, especially in birds. Imprinting pertains to the phenomenon whereby early exposure to arbitrary perceptions determines later behaviour and preferences (see Sluckin, 2007, for a review). Famously, for example, Lorenz demonstrated that greylag geese chicks could be induced to follow a walking human being if the human being was the first thing the geese saw that moved (in normal circumstances, the first moving thing the geese see is their mother). Subsequent studies demonstrated that birds can be imprinted to prefer, among other things, striped walls to plain walls (see Sluckin, 2007). Such imprinting effects appear to be over and above those of classical conditioning—first, imprinting may be extremely rapid, as was the case with Lorenz's geese; second, it may occur without an associated reflex, as was again the case with Lorenz's geese. Moreover, although early claims suggested imprinting involves a "critical period" and is relatively inflexible (it is "all or nothing"), later research suggested 1) critical periods are not especially critical and 2) that imprinting can be flexible; also, much depends on the nature of the imprinting stimuli, the particular behaviour, and the particular species (Sluckin, 2007). There are reports that young human beings, incidentally, appear to be imprinted as regards to later mate-choice preference—when adult, they avoid mating with those they have known as children (see Diamond, 1992). Related to this, a recent study of two closely related species, great tits (*Parus major*) and blue tits (*Cyanistes caeruleus*), suggests that chicks learn their species identity through imprinting on their mother's physical characteristics (Hansen *et al.*, 2007). Such imprinting affects the birds' later choices of whom they perceive as future mates and whom they perceive as territorial threats. So, imprinting appears a universal phenomenon among animals, so it is at least plausible that chicken food preferences could be altered by early experience, regardless of "instinctive" preferences.

In experiments 1 and 4, the broiler chicks showed a clear preference for a high fat diet (8%) in the first week of their life even when position of the troughs was changed daily. Consequently, experiments were carried out in which the only difference between the two diets was that of colour (green and red), form (dry crumbs and wet; dry pellet and wet; and crumb and pellet,), and flavour (non and garlic). These factors were investigated in experiment 6, 7, 8, 9 and 10.

7.2 Experiment 6

The following experiment was conducted to investigate whether a coloured diet with the same composition (8.0% fat) affected the preference or aversion to particular food colours.

7.2.1 Materials and Methods

Materials and methods were as described for experiment 2, except that different behaviours were recorded and carcass composition and weight of body components not recorded. The behaviours recorded comprised.1) feeding, 2) drinking, and 3) pecking.

7.2.1.1 Treatments

Two treatments were used in this experiment: T1 (green coloured starter crumbs, 8.0% fat, on the 1st day followed by red coloured starter crumbs, 8.0% fat, on the 2nd day) and T2 (red coloured starter crumbs, 8.0% fat on the 1st day followed by green coloured starter crumbs, 8.0% fat, on the 2nd day). Chicks were then offered a choice between both diets for 5 days after 2h of fasting. There were 3 replicates with 10 birds each. See Plate 7.1. See Box 7.1 for a summary of the treatments.

Plate 7. 1. Feeders offering free-choice red and green diets.

Box 7. 1. Treatments: feeding procedure; experiment 6.

	Treatments	
Day	T1	T2
1	HF starter crumb diet. Green	HF starter crumb diet. Red
2	HF starter crumb diet. Red	HF starter crumb diet. Green
3	2h fast followed by HF starter crumb diet. Green and red. Free-choice	2h fast followed by HF starter crumb diet. Green and red. Free-choice
4–7	HF starter crumb diet. Green and red. Free-choice	HF starter crumb diet. Green and red. Free-choice

HF: high fat

The coloured diets were prepared by mixing 30ml of green or red food colouring with120 ml water and spraying onto 1kg of the diet which was then allowed to dry at room temperature (Sahin and Forbes,1998). Feed intake was weighed after 1 and 24h into the free-choice period.

7.2.1.2 Statistical analysis

Treatment effects of all variables were determined by a series of ANOVAs, in an analogous manner to that described for experiment 4. The dependent variables were as described in Section 4.3 (feed intake, body weight, weight gain, etc., except they did not include carcass composition and weight of body components). As in experiment 4, feed intake was the dependent variable of most interest, save that the factor involved was colour (green or red), not fat level. The independent variable was treatment.

7.2.2 Results

7.2.2.1 The performance of broiler chicks

A summary of the results are presented in Table 7.1 No significant differences were observed with total feed intake (g) per bird after 7 days, in the two treatments. The total feed intake per bird was 147g of T1 and 138g of T2. Also, no significant differences were observed with respect to final body weight, body weight gain, and feed conversion ratio in the two treatments.

Table 7. 1. Total feed intake, final body weight, weight gain and feed conversion ratio of birds in the two treatments.

Parameters	T1	T2	SE
Total feed intake (g/bird)	147	138	± 7.6
Final body weight (g/bird)	177	185	± 8.6
Final body gain (g/bird)	134	142	± 8.6
Feed conversion ratio (g/g)	1.1	1.0	± 0.1

($p < .05$).

The effect of coloured diet on feed intake of the chicks fed on green and red diet during the free-choice period is summarised in Table 7.2. Feed intake of green coloured food for chicks fed green coloured starter crumbs diet (8.0% fat) on the

1st day followed by red coloured starter crumbs diet (8.0% fat) on the 2nd day was more (19g) than that consumed from chicks fed red coloured starter crumbs diet (8.0% fat) on the 1st day followed by green coloured starter crumbs diet (8.0% fat) on the 2nd day (7g). While red coloured diet feed intake was greater in T2 (17g) than T1 (6g) birds.

Table 7. 2. Effect colour of diet on average feed intake of the chicks fed on green and red coloured diet during the free-choice period (5 days).

Colour of diet	T1	T2	SE
	(g/bird/d)		
Green	19 ^{a}	7 ^{b}	± 1.4
Red	6 ^{b}	17 ^{a}	± 1.4

^{a,b} Mean values not sharing a common superscript letter in same row are significantly different ($p < .05$)

There was a significant difference ($p < .05$) between the weights of two diets eaten during the first hour and 24h after the initial diet whether it was green or red in both treatments, Table 7.3.

Table 7. 3. Effect of coloured diet on feed intake of the chicks after 1 and 24h into the free-choice period.

Colour of diet	1h			24h		
	T1	T2	SE	T1	T2	SE
			(g/bird)			
Green	1.5 ^{a}	0.4 ^{b}	± 0.2	10.7 ^{a}	4.0 ^{b}	± 1.5
Red	0.2 ^{b}	1.4 ^{a}	± 0.2	4.3 ^{b}	9.7 ^{a}	± 1.5

^{a,b} Mean values not sharing a common superscript letter in the same row are significantly different ($p < .05$)

7.2.2.2 The behaviour of broiler chicks

A summary of behavioural results in relation to feeding, drinking, and pecking behaviours are presented in Table 7.4. Statistical analysis of the results showed no differences detected between the two treatments.

Table 7. 4. Mean feeding, drinking and pecking behaviours during 6 days observation.

Parameters	T1	T2	SE
Feeding (no/bird /h)	15	13	± 8.3
Drinking (no/bird /h)	7	5	± 4.1
Pecking (no/bird /h)	12	13	± 5.0

($p < .05$); no: number; b: bird; h: hour

There was a significant difference ($p < .05$) within both treatments on the mean feeding behaviour associated with red and green diets (T1: 12 no/b/h green versus 3 no/b/h red and T2: 4 no/b/h green versus 7 no/b/h red). There was also a significant difference ($p < .05$) between T1 and T2 in feeding behaviour in relation to green coloured food during the free-choice period, where mean feeding behaviour response was 12 and 4 no/b/h respectively and a significant difference ($p < .05$) between T1 and T2 of feeding behaviour in relation to red coloured diet. However, there were no significant difference between feeding behaviour of green and red coloured diet between T1 and T2 (T1 12 no/b/h green versus T2 7 no/b/h red and T1 3 no/b/h red versus T2 4 no/b/h green). See Table 7.5.

Table 7. 5. Mean feeding behaviour during the free-choice period (5 days).

Colour of diet	T1	T2	SE
	(no/b/h)		
Green	12 [a]	4 [b]	± 6.3
Red	3 [b]	7 [a]	± 4.8

[a,b] Mean values not sharing a common superscript letter are significantly different ($p < .05$); no: number; b:bird; h: hour

7.2.3 Discussion

The colour of the diet given initially was shown to lead to significant preferences, where there was significant difference ($p < .05$) between T1 and T2 on feed intake of green coloured diet (1.5 and 0.4g /bird respectively) and a significant difference ($p < .05$) between T1 and T2 of feed intake of red coloured diet (0.2 and 1.4g /bird respectively). However, there was no significant difference between combined average feed intakes of green and red coloured diets after 1h into the free-choice period of both diets. Similar results were observed after 24h into the free-choice period of both diets.

This results show that the preference of the coloured diet was affected by initial diet colour given to the chicks on the first day in this experiment. This result is in disagreement with that of Forbes and Shariatmadari (1994), who found that there was no significant difference between the weights of two diets eaten during the first hour after the initial diet given was green or red. Earlier studies by Capreta (1969) and Taylor *et al.,* (1969) revealed that, although chicks were initially attracted to the colour red, exposure to blue for a training period shifted their preference in that direction, and exposure to red for a training period reinforces their preference for red.

This experiment showed that chicks could differentiate between colours of diet in such a way as to suggest that they have learned to associate food with the initial coloured diet they were presented with. Since there were no nutritional differences among the different coloured diets, this trial specifically addressed predisposed colour preferences for red and green food types in young chicks. Since no differences in total food consumed of any one colour type were observed during the beginning or end of the free-choice period, predisposed colour preference about either red or green coloured food does not appear to be present in these chicks. At a theoretical level, imprinting could figure largely in the chicks' food preferences; alternatively or in addition, classical conditioning could do so.

Of course, the decision to use green and red as opposed to other colours was to an extent arbitrary. But evidence of innate colour preferences in chickens is, as mentioned, mixed—although they seem to have innate preferences, what the preferences are is uncertain, indeed, if they have them. There is also the evidence of their ability to see UV light, and to prefer it, at least in mate selection. This raises the possibility that poultry's colour preferences in food selection lie outside the human visual spectrum. To this, one can make three points.

First, because poultry prefer a given colour in one context does not imply they must prefer it in another. Second, in terms of immediate practice for commercial poultry producers, it is an irrelevance. Food additive manufacturers do not, at present, manufacture "UV dyes". However, incorporation of poultry's responsiveness to UV light offers intriguing possibilities for future research.

Third, and most important, the purpose of the present experiment was to determine whether early exposure to *any* colour affects later poultry preference towards food of otherwise identical composition. The present experiment suggests the answer is No.

Since colour alone may well not be responsible for generating the desired maximal intake of feed in young birds, it is necessary to consider other factors including the texture of the feed. This can be particularly important in young birds, which may find difficulty in consuming particular types of feed based upon its texture. Consequently the following chapter explores the role of feed texture in the feeding of very young chicks.

Chapter 8: Effect of Wet and Dry Starter Diets Given in a Free Choice Selection Regime on Feeding Preference of Male Broilers from 3 to 7 Days Old

8.1 Introduction

In large-scale poultry production there has been a tendency to shy away from feeding birds wet mashes, principally because there are no expected nutritional advantages compared to other feed forms; there are also application problems. However, a broad body of work has demonstrated that food when soaked and re-dried tends to be more efficiently utilized. At the same time, it has frequently been observed that conventional foods that are homogenised with water (typically 1.5–2.0 kg of water per kilogram of dry food), to produce a rough slurry consistency, increase both the feeding tendency and the proportion of nutrients retained by birds after consumption (Forbes, 2003). Due to these phenomena, feeds with lower nutrient density (e.g., with high cereal content) could be utilized to obtain targeted growth rates.

It is unlikely that the increased digestive efficiency seen in wetted food trials is due to increased activation of endogenous feed enzymes; it is more likely that wet homogenized feeds allow the more efficient dispersion of digestive juices throughout the food in the gastrointestinal tract and that this leads to higher absorption rates. Production benefits derived from wet homogenised feeds have been observed in both male and female broilers and are frequently seen to be most effective when used as early as possible in development. Also, sexually mature ducks and hens seem to feed more efficiently on wet feed (Forbes, 2003; Pousga *et al.*, 2005).

Wet homogenized feeds have additional commercial advantages. Use of this preparation technique means that feeds can contain a greater proportion of cereals without the need to use pelleting; the preparation also allows more daily opportunities to qualitatively change the composition of the feed by allowing the addition of amino acids or medications. Further, wetting helps reduce dust levels in food, and these can be problematic in intensive poultry houses. Against such advantages, the wet homogenised preparation of feed can lead to more wet litter and dirtier birds, both of which contribute to the spread of disease. A further disadvantage is the potential high costs of the equipment required for both preparation and delivery of the feed. Consequently, there has been a general reluctance to adopt wet homogenization of feed in commercial environments, although there may be particular benefits for its application in high temperature environments.

Typically the application of wet homogenized feeds has been utilized for backyard chicken husbandry. Abasiekong (1989) showed that feed wetting led to better performance characteristics in broilers, and Tadtiyanant *et al.* (1991) suggest that wet feeding is beneficial to laying hens in hot environments. However, as standard, albeit old, texts (Jull, 1938; Robinson, 1948) have stated that there are no expected performance or efficiency improvements to be seen from wet homogenization of feed, there has been a general reluctance to consider its application in commercial situations. This has been compounded by the further argument in relation to the costs of the special machinery required for the automated preparation and delivery of the feed, as well as the potential for increased fungal growth in wet prepared food (Caldwell *et al.*, 1986).

Recent work by Yalda and Forbes (1995a, 1995b, 1996) showed considerable benefits in the use of wet feeds from both performance and efficiency perspectives, and Yasar and Forbes (1999, 2000) have partially described mechanisms by which these benefits are achieved (and see Forbes, 2003, for a review). The problems associated with automated preparation and delivery of wet feed has also been addressed by Thorne *et al.* (1989), who provided details of automated feeding systems for delivery of wet by-product diets to caged laying hens. Interestingly, the use of wet homogenized feeds opens the prospect of utilization of liquid by-products from the food industry in poultry feeds; this is currently used widely in the pig industry.

8.2 Experiment 7: Effect of Wet and Dry Crumb Starter Diets Given in a Free Choice Selection Regime on Feeding Preference of Male Broilers from 3 to 7 Days Old

Due to limited information about the effects of wet diets on male broiler chicks' feeding preferences, especially in the first week of their life, two experiments were conducted in order to determine wet versus dry diet (starter crumbs or pellet, 8.0% fat; see Appendix 1) preferences of juvenile broiler chicks.

8.2.1 Materials and Methods

Materials and methods were as described for experiment 6.

8.2.1.1 Treatments

Chicks were first familiarised with the dry and wet crumb diets by sequentially presenting the alternative diets over a 2-day period to allow them to become accustomed to the sensory properties of each diet. Two treatments were used in this experiment (3 replicates with 10 birds each): T1 (starter crumbs dry (8.0% fat) on the 1st day followed by starter crumbs wet (8.0% fat) on the 2nd day) and T2 starter crumbs wet (8.0% fat) on the 1st day followed by starter crumbs dry (8.0% fat) on the 2nd day). The birds were then offered a choice between dry and wet diet for 5 days after 2h fasting, as shown in Box 8.1.

Box 8. 1. Treatments: feeding procedure; experiment 7.

	Treatments	
Day	T1	T2
1	HF starter crumb diet. Dry	HF starter crumb diet. Wet
2	HF starter crumb diet. Wet	HF starter crumb diet. Dry
3	2h fast followed by HF starter crumb diet. Dry and wet. Free-choice	2h fast followed by HF starter crumb diet. Dry and wet. Free-choice
4–7	HF starter crumb diet. Dry and wet. Free-choice	HF starter crumb diet. Dry and wet. Free-choice

HF: high fat

The wet diet was prepared daily by mixing 1 part by weight of the dried diet with 1.8 parts of tap water; refusals were weighed and discarded the next day (Yalda and Forbes, 1995). Feed intake was weighed after 1 and 24h of the start of the free-choice period.

8.2.1.2 Measurements

8.2.1.2.1 Feed and water intake

Group feed and water intakes were recorded daily throughout the experimental period.

All feed intake for wet diet were calculated on an air–dried basis.

8.2.1.3 Statistical analysis

The procedures as used in experiment 4 were used in this experiment. The dependent variables were the same as in experiment 4. Feed intake was the dependent variable of most interest, save that the factor involved was water content, not fat level. The independent variable was treatment (T1 and T2; between measures).

8.2.2 Results

8.2.2.1 The performance of broiler chicks

A summary of the results is presented in Table 8.1. No significant differences were observed with total feed intake (g) per bird after 7 days, in the two treatments. The total feed intake per bird was 116g in T1 and 119g in T2. Additionally, no significant differences were observed in total water intake, body weight, weight gain, and feed conversion ratio between the two treatments.

Table 8. 1 Total feed intake, final body weight, weight gain and feed conversion ratio of birds on the two diet regimes during whole trial period (7 days.

Parameters	T1	T2	SE
Total dry feed intake (g/bird)	116	119	± 3.6
Total water intake (ml/bird) *	19	19	± 1.1
Final body weight (g/bird)	139	143	± 3.2
Total weight gain (g/bird)	100	104	± 2.9
Feed conversion ratio (g/g)	1.2	1.1	± 0.04

($p < .05$)

The effect of physical form of diet on feed intake during the free-choice period is summarised in Table 8.2 and Figure 8.1. The physical form of diet had a significant ($p < .05$) effect on feed intake. Broiler chicks ate greater quantities of wet diet (17 and 18g/bird) than dry diet (3 and 2g/bird) in both treatments.

Table 8. 2. Effect of physical form of diet on average feed intake of the chicks during the free-choice period (5 days).

Physical form of diet	T1 (g/bird/d)	T2	SE
Dry	3 [a]	2 [a]	± 0.7
Wet	17 [b]	18 [b]	± 0.7

[a,b] Mean values not sharing a common superscript letter are significantly different ($p < .05$)

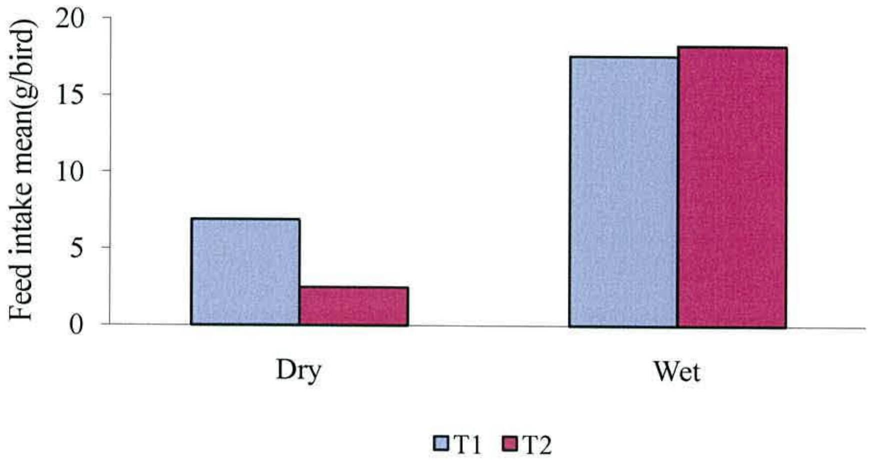

Figure 8. 1. Effect of physical form of diet on average feed intake of the chicks fed on dry and wet crumb diets during the free-choice period (5 days)

There was a significant difference ($p < .05$) between the weights of the two diet forms eaten during the first hour and 24h into the free-choice period within treatments but not between treatments. See Table 8.3 and Figure 8.2.

Table 8. 3 Effect of physical form of diet on feed intake of the chicks after 1h and 24h into the free-choice period.

Physical form of diet	1h			24h		
	T1	T2	SE	T1	T2	SE
	(g/bird)					
Dry	0.4 [a]	0.2 [a]	± 0.3	4 [a]	3 [a]	± 1.5
Wet	4 [b]	4 [b]	± 0.3	12 [b]	14 [b]	± 1.5

[a,b] Mean values not sharing a common superscript letter are significantly different ($p < .05$)

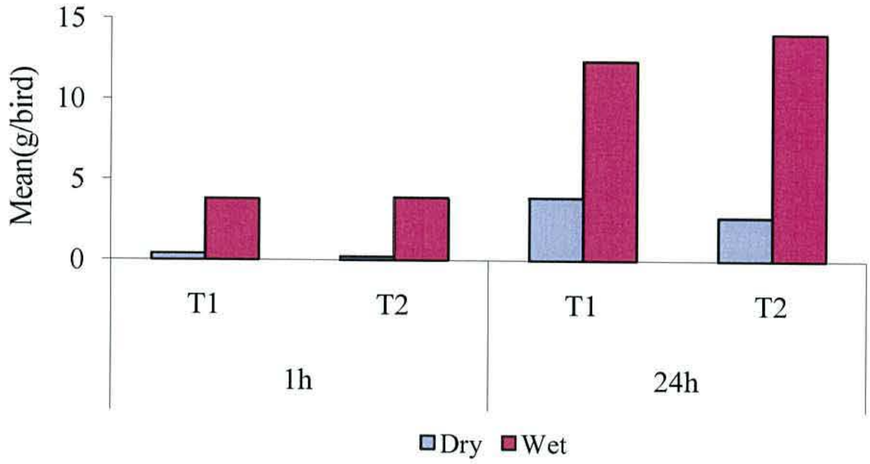

Figure 8. 2. Effect of physical form of diet on feed intake of the chicks fed on dry and wet crumb diets after 1 and 24h of beginning the free-choice period.

8.2.2.2 The behaviour of broiler chicks

A summary of results feeding, drinking and pecking behaviours are presented in Table 8.4. Statistical analysis of the results revealed no differences between the two treatments.

Table 8. 4. Mean hourly feeding, drinking and pecking responses of birds in both treatments over 6 days observation.

Parameters	T1	T2	SE
Feeding (no/b/h)	11	11	± 5.0
Drinking (no/b/h)	4	4	± 2.3
Pecking (no/b/h)	10	10	± 3.4

($p < .05$); no: number; b: bird; h: hour

Feeding behaviour associated with the dry or wet diet was not significantly different between T1 and T2, but there were significant differences ($p < .05$) in feeding behaviour associated with both diet forms within both treatments where the mean feeding responses were higher on wet compared with dry diet forms (T1: 10 no/b/h wet versus 0.7 no/b/h dry diet and T2: 10 no/b/h wet versus 0.5 no/b/h dry diet). See Table 8.5.

Table 8. 5. Mean hourly feeding behaviour associated with the two forms of diet available during free-choice period (5 days).

Physical form of diet	T1 (no/b/h)	T2 (no/b/h)	SE
Dry	0.7^{a}	0.5^{a}	± 1.3
Wet	10^{b}	11^{b}	± 4.6

^{a,b} Mean values not sharing a common superscript letter are significantly different ($p < .05$); no: number; b:bird; h: hour

8.2.3 Discussion

Feed intake was influenced by addition of water to the air-dried diet; chicks consumed significant ($p < .05$) wet compared with dry diet in both treatments. These observations agree with the results of Yalda and Forbes (1995a, 1995b).

Chicks fed on wet diet during the first day decreased their feed intake when they were switched to dry diet on the second day, while the chicks fed on dry diet during the first day increased their feed intake when they switched to wet diet in the second day. During the free-choice period, birds in both treatments ate considerably more of the wet than dry diets. This is a clear indication of the preference of broiler chicks for the wet diet in the two treatments, even though the chicks in T2 had not been previously exposed to the wet diet. This strongly suggests that addition of water to air dried feeds encourages feeding and improves food intake in very young chicks.

However, since texture can be both a component of the hydration level and the physical form of the dietary feed itself, it was felt that it was necessary to consider alternative dietary physical attributes in conjunction with hydration level. For this reason, in the following experiment pellet forms of the diets where exchanged for the crumb diets of the previous experiment.

8.3 Experiment 8: Effect of Wet and Dry Pellet Starter Diets Given in a Free Choice Selection Regime on Feeding Preference of Male Broilers from 3 to 7 Days Old

This experiment was conducted, first, to confirm the conclusions of experiment 7, and, second, to see if physical form pellet (rather than crumb) of the wet feed played any role in the feeding preferences of young chicks.

8.3.1 Materials and Methods

Materials and methods were as described for experiment 6.

8.3.1.1 Treatments

Chicks were first familiarised with the dry and wet pellet diets by sequentially presenting the alternative diets over a 2-day period to allow them to become accustomed to the sensory properties of each diet. In this experiment, two treatments were again established: T1 starter pellet dry (8.0% fat) on the 1st day followed by starter pellet wet (8.0% fat) on the 2nd day; and T2 starter pellet wet (8.0% fat) on the 1st day followed by starter pellet dry (8.0% fat) on the 2nd day. Chicks were then offered a choice between dry and wet pellet diets for 5 days after 2h fasting. There were 3 replicates with 10 birds each. See Box 8.2 for a summary of the treatments.

Box 8. 2. Treatments: feeding procedure; experiment 8.

	Treatments	
Day	T1	T2
1	HF starter pellet diet. Dry	HF starter pellet diet. Wet
2	HF starter pellet diet. Wet	HF starter pellet diet. Dry
3	2h fast followed by HF starter pellet diet. Dry and wet. Free-choice	2h fast followed by HF starter pellet diet. Dry and wet. Free-choice
4–7	HF starter pellet diet. Dry and wet. Free-choice	HF starter pellet diet. Dry and wet. Free-choice

HF: high fat

8.3.1.2 Measurements

8.3.1.2.1 Feed and water intake

As described previously.

8.3.1.3 Statistical analysis

The statistical analysis was the same as that of experiment 7.

8.3.2 Results

8.3.2.1 The performance of broiler chicks

The results of the treatment effects on feed intake, total water intake, final body weight, body weight gain and feed conversion ratio are presented in Table 8.6. The broiler chick fed on the dry pellet diet on the first day followed by wet pellet diet (both 8.0 % fat) on the second day ate more (but not significantly) than chicks fed on the wet diet on the first day followed by dry diet (8.0% fat) on the second day (138 vs. 124g/bird).

Table 8. 6. Total feed intake, final body weight, weight gain and feed conversion ratio of birds in the two treatments.

Parameters	T1	T2	SE
Total dry feed intake (g/bird)	138	124	± 2.1
Total water intake (ml/bird) *	21	19	± 0.5
Final body weight (g/bird)	203	196	± 12.1
Final weight gain (g/bird)	161	153	± 11.9
Feed conversion ratio (g/g)	0.9	0.8	± 0.06

($p < .05$)

The effect of physical form of diet on feed intake during free-choice period is summarised in Table 8.7 and Figure 8.4. Physical form of diet had a significant ($p < .05$) effect on feed intake. Broiler chicks ate more of the wet pellet diet than the dry pellet diet in both treatments (T1: 18 versus 7g/bird respectively and T2: 18 and 3g/bird respectively). At the same time, birds fed dry pellet diet first significantly ($p < .05$) consumed more dry diet in the free-choice period compared with those initially fed on the wet diet (7 versus 3g/bird).

Table 8. 7. Effect of physical form of diet on average feed intake of the chicks fed on dry and wet pellet diets during the free-choice period (5 days).

Physical form of diet	T1 (g/bird/d)	T2	SE
Dry	7 [a]	3 [c]	± 0.9
Wet	18 [b]	18 [b]	± 0.9

[a,b,c] Mean values not sharing a common superscript letter are significantly different ($p < .05$)

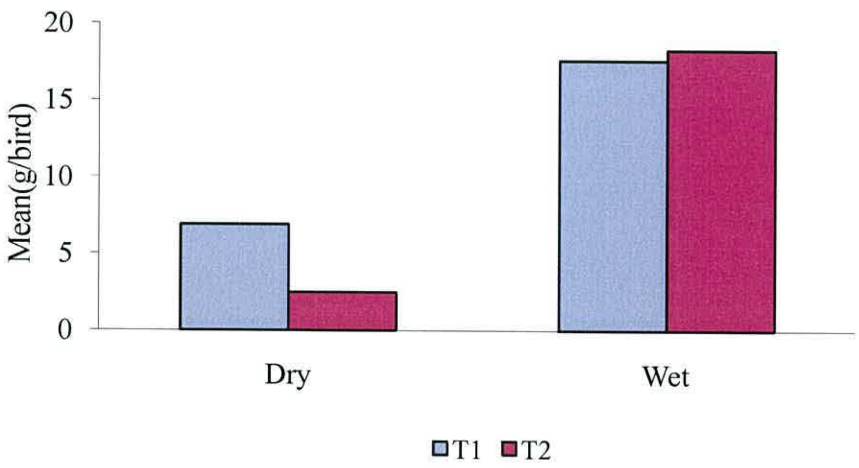

Figure 8. 3. Effect of physical form of diet on average feed intake of the chicks fed on dry and wet pellet diets during the free-choice period (5 days).

There was a significant difference ($p < .05$) between the weights of two diet forms eaten during the first hour and 24h into the free-choice feeding period within treatments for both observation periods and between treatments after 24h for dry diets only. See Table 8.8 and Figure 8.4.

Table 8. 8. Effect of physical form of diet on feed intake of the chicks fed on dry and wet pellet diets after the first hour and 24h into the free-choice period.

Physical form of diet	1h			24h		
	T1	T2	SE	T1	T2	SE
	(g/bird)					
Dry	0.2 [a]	0.3 [a]	± 0.4	8 [a]	3 [c]	± 0.8
Wet	7 [b]	6 [b]	± 0.4	13 [b]	14 [b]	± 0.8

[a,b,c] Mean values not sharing a common superscript letter are significantly different ($p < .05$)

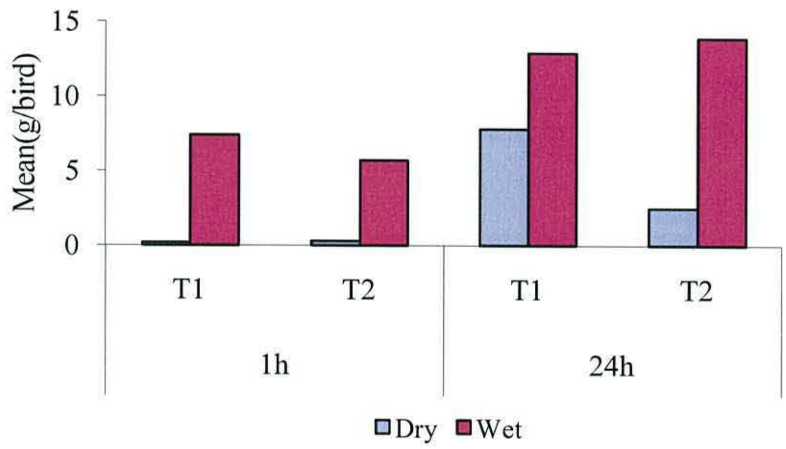

Figure 8. 4. Effect of physical form of diet on feed intake of the chicks fed on dry and wet pellet diets after the first hour and 24h into the free-choice period.

8.3.2.2 The behaviour of broiler chicks

A summary of results in relation to total feeding, drinking and pecking behaviours is presented in Table 8.9. Statistical analysis of the results showed no significant differences detected between the two treatments.

Table 8. 9. Mean of feeding, drinking and pecking behaviours during 6 days observation.

Parameters	T1	T2	SE
Feeding (no/b/h)	10	9	± 4.5
Drinking (no/b/h)	4	5	± 1.3
Pecking (no/b/h)	8	8	± 3.2

($p < .05$); no: number; b:bird; h: hour

Feeding behaviour of birds on dry and wet diets was not significantly different between treatments. However, there were significant differences ($p < .05$) in feeding behaviour within treatments with birds showing greater feeding responses on wet diets compared with dry in both treatments (T1: 10 no/b/h versus 0.1 no/b/h and T2: 10 no/b/h versus 0.2 no/b/h respectively). See Table 8.10.

Table 8. 10. Mean feeding behaviour responses of birds in both treatments during the free-choice period (5 days).

Diet	T1	T2	SE
	(no/b/h)		
Dry	0.1^{a}	0.2^{a}	± 1.4
Wet	10^{b}	10^{b}	± 4.3

^{a,b} Mean values not sharing a common superscript letter are significantly different ($p < .05$); no: number; b:bird; h: hour

8.3.3 Discussion

Again, in this experiment feed intake was increased with addition of water to the dry diet. The increase in feed intake due to addition of water to the dry pellet diet was associated with an increase in body weight and feed conversion ratio; these results accord with the results of Yalda and Forbes (1995a, 1995b).

8.4 General Discussion

Both experiments show that feed intake was improved by the addition of 1.8 parts of water to 1 part air-dry diet. This improvement was significant ($p < .05$) in both experiments. One of the reasons to explain why chicks eat more wet diet may be that the wet diet is passed and absorbed more quickly through the digestive system than is the dry diet (Heuser, 1945; Clemens *et al.*, 1975; Ferrando *et al.*, 1987).

A second reason may be that chicks that feed on wet diets appear to spend less time in drinking, as suggested by the lower drinking behaviour responses observed in this experiment compared with previous experiments reported here. This not only increases available time for foraging but also has the potential to reduce overall metabolic costs of activity.

It can be concluded that the addition of water to the dry diet increases feed intake and the possible mechanisms for this increase could include the improved action of endogenous enzyme and reduced digesta viscosity and/or osmotic pressure of the diet. The results reported here also confirm the benefits of adding water to diet in terms of broiler feed intake.

A further textural component of feed that may have additional effects on bird performance is the use of mash (rather than crumb or pellet forms). The use of mash is controversial since it is much more difficult to use (for a variety of reasons). Nevertheless, it is important to consider all possible beneficial opportunities with regards to diet selection. Consequently, the following chapter considers what effects the use of mash feeds may have on early stage bird development.

Chapter 9: The Effect of the Physical Form of Diet on Feeding Preference of Male Broiler Chicks

9.1 Introduction

Management of feeding is invariably the most important daily component in any poultry production system. The effective control of feeding has the greatest influence in terms of both biological and economical efficiency. In general, animals eat to satisfy the energy requirement of physiological processes, meet physical challenges, respond to volume receptor feedback, or to reach a state of fullness or satiety. While feed intake management is of major importance across all livestock enterprises trying to maximize profitability, the issues associated with food intake have special significance in poultry production facilities (either meat or eggs), since feed alone can account for upwards of 70% of the total cost of the poultry production (Forbes, 1986). Consequently, an understanding of feeding strategies would potentially aid the development of feeding regimes that optimize the feed utilization and productivity within the poultry industry.

Voluntary feed intake is defined as the weight of food eaten by an animal or group of animals during a given period of time during which they have free access to the food (Forbes, 1986). A significant proportion of daily food intake is allocated to reproduction and body maintenance. There are a large number of factors that both directly and indirectly modify food intake. Some of these factors can be genetically manipulated; others can be modified through manipulation of the nutritional state of the food or the environmental conditions under which feed occurs. One factor that influences food intake is the physical form of the food. In poultry the form of the food normally offered is frequently manipulated throughout the life of the birds to influence their food intake efficiency. The rations can be delivered in many forms. These include all dry mash, all wet mash, pellets, dry mash and wet mash, dry mash and pellets, and combinations of grains with the other types of ration. The decision to use particular ration forms depends upon the performance advantages as well as the economic cost-benefit relationships and the ability of the birds to handle each ration form regime.

Free choice feeding has the potential to allow individual birds to select their optimum protein, fat, and overall energy intakes. Yet the use of free-choice has until recently been considered as too difficult to apply or manage at commercial scales of operation. Many authors have reported significant performance improvements with free-choice feeding (Leeson and Summers, 1983, Karunajeewa and Tham, 1984, Cumming, 1983, 1984, Mastika and Cumming, 1981, 1987; Rose, 1985; Shariatmadari and Forbes, 1993). However, the overall assessment of free-choice feeding has been complicated by additional studies that suggest poultry cannot self select their optimal nutrient requirements (Maurice *et al.*, 1979, El-Husseinv and Ghazalah, 1980, Scholtyssek, 1982, Blake *et al.*, 1984; Robinson, 1985).

9.2 Experiment 9

This study highlighted the effect of the physical form of the food (crumb and pellet) on the preference of the broiler chicks during the first week of their life.

9.2.1 Materials and Methods

Materials and methods were as described for experiment 6.

9.2.1.1 Treatments

Chicks were first familiarised with the diets by sequentially presenting the alternative diets over a 2-day period; this allowed them to become accustomed to the sensory properties of each diet. Two treatments (3 replicates with 10 birds each) were used in this experiment: T1: starter crumbs diet (8.0% fat) on the 1st day followed by starter pellet diet (8.0% fat) on the 2nd day; and T2: starter pellet diet (8.0% fat) on the 1st day followed by starter crumbs diet (8.0% fat) on the 2nd day. The birds were then offered a choice between crumbs and pellets diets for 5 days after 2h fasting, as shown in Box 9.1

Box 9. 1. Treatments: feeding procedure; experiment 9.

	Treatments	
Day	T1	T2
1	HF starter crumb diet.	HF starter pellet diet
2	HF starter pellet diet	HF starter crumb diet
3	2h fast followed by HF starter diet. Pellet and crumb. Free-choice	2h fast followed by HF starter diet. Pellet and crumb. Free-choice
4–7	HF starter diet. Pellet and crumb. Free-choice	HF starter diet. Pellet and crumb. Free-choice

HF: high fat

9.2.1.2 Statistical analysis

Statistical analysis was the same as that used in experiment 7. The dependent variables were the same, save that the food variable of interest was crumb or pellet, not water content.

9.2.2 Results

9.2.2.1 The performance of broiler chicks

The results of the effect treatment on feed intake, body weight, body gain and feed conversion ratio are presented in Table 9.1. The broiler chick fed on the pellet diet on the first day followed by crumbs diet (8.0% fat) on the second day ate more (but not significantly) than chicks fed on the crumbs diet on the 1st day followed by pellet diet (8.0% fat) on the 2nd day (155 vs. 135g/bird).

Table 9. 1. Total feed intake, final body weight, weight gain and feed conversion ratio of birds in the two treatments.

Parameters	T1	T2	SE
Total feed intake (g/bird)	135	155	± 6.1
Final body weight (g/bird)	191	206	± 3.9
Final weight gain (g/bird)	148	163	± 3.9
Feed conversion ratio (g/g)	0.9	1.0	± 0.03

($p < .05$)

The effect of physical form of diet on feed intake during the free-choice period is summarised in Table 9.2. Physical form of diet had a significant ($p < .05$) effect on feed intake. Broiler chicks ate the crumbs diet to a greater extent (21g/bird T1 and 22g/bird T 2) than the pellet diet (3g/bird T 1 and 5g/bird T 2).

Table 9. 2. Effect of physical form of diet on average feed intake of the chicks fed on crumb and pellet diet during the free-choice period (5 days).

Physical form of diet	T1	T2	SE
	(g/bird/d)		
Crumbs	21 ^{a}	22 ^{a}	± 1.6
Pellet	3 ^{b}	5 ^{b}	± 1.6

^{a,b} Mean values not sharing a common superscript letter are significantly different ($p < .05$)

There was no significant difference between the weights of the two diet forms eaten during the first hour after the initial diet was either crumbs or pellet (i.e. T1 or T2). However, there was a significant difference ($p < .05$) between the weights of the two diet forms eaten after 24h within treatments (11g crumbs/bird vs. 4g pellet/bird T1) and (12g crumbs/bird vs. 4g pellet/bird T2), but no differences detected between treatments. See Table 9.3.

Table 9. 3. Effect of physical form of diet on feed intake of the chicks fed on dry and wet diet after the first hour and after 24h of free-choice feeding.

	1h			24h		
Physical form of diet	T1	T2	SE	T1	T2	SE
			(g/bird)			
Crumbs	0.6	0.7	± 0.1	11 [a]	12 [a]	± 0.4
Pellet	0.3	0.2	± 0.1	4 [b]	4 [b]	± 0.4

[a,b] Mean values not sharing a common superscript letter are significantly different ($p < .05$)

9.2.2.2 The behaviour of broiler chicks

A summary of results in relation to feeding, drinking and pecking behaviours are presented in Table 9.4. Statistical analysis of the results showed no differences between the two treatments.

Table 9. 4. Mean of feeding, drinking and pecking behaviours during 6 days.

Parameters	T1	T2	SE
Feeding (no/b/h)	1.0	0.7	± 0.3
Drinking (no/b/h)	0.5	0.5	± 0.2
Pecking (no/b/h)	0.8	0.9	± 0.3

($p < .05$); no: number; b: bird; h: hour

Feeding behaviour on crumbs diet was not significantly different between T1 and T2 birds and no significant difference was observed between T1 and T2 birds feeding behaviour on a pellet diet. However, there were significant differences

($p < .05$) between feeding behaviour of crumbs and pellet diet within both treatments T1 and T2, where the mean responses were T1: 1.0 no/b/h crumb versus 0.1 no/b/h pellet and T2: 1.0 no/b/h crumb versus 0.1 no/b/h pellet. See Table 9.5.

Table 9. 5. Mean of feeding behaviour during free-choice period (5 days).

Diet	T1	T2	SE
	(no/b/h)		
Crumbs	10 [a]	10 [a]	± 1.3
Pellet	1 [b]	1 [b]	± 1.5

[a,b] Mean values not sharing a common superscript letter are significantly different ($p < .05$); no: number; b:bird; h: hour

9.2.3 Discussion

The results of this experiment revealed an obvious preference for the crumb diet compared to the pellet diet by male broiler chicks during the free-choice period (5 days). Physical form of diet had a significant ($p < .05$) effect on feed consumption. Male broiler chicks ate more crumbs diet than pellet diet. This finding accords with that of Sell and Thompson (1965), who found that increasing the fat level by 10% of the ration decreased the chicks' response to pelleting, although, in the case of efficiency of energy utilisation, the beneficial influence of pelleting was still apparent. Furthermore, a 10% fat ration as pellets or ground pellets increased weight gain only slightly and failed to increase food consumption or to improve efficiency of food utilisation in comparison with feeding the same ration as a mash. Combs *et al.* (1958) also reported that pelleting a ration containing 10% fat did not improve chick performance.

Although feed intake was significantly ($p < .05$) influenced by the form of the diet, final body weight, body gain and feed conversion ratio were not significantly influenced by the form of the diet within the two treatments. Total changes in food intake from combined pellet and crumbs diets was only marginally different.

Several studies have shown that birds are able to choose a combination of at least two foods that reflect their needs (Rose and Kyriazakis, 1991). Diet selection is affected by preference, experience, and social transmission of feeding behaviour (Chapple and Lynch, 1986). Social transmission, however, need not involve imitation. A recent study (Allen and Clarke, 2005) of white-tailed ptarmigan (*Lagopus leucurus*) suggests that hens call their chicks' attention to good food sources simply by giving food calls, to which their chicks respond. Such learning, though social, does not involve imitation. Also, although imitation does occur in non-human animals, it appears very limited, even in the great apes (Whiten *et al.*, 2004).

Shariatmadari and Forbes (1992a, 1992b) have observed that broilers given free access to high and low protein food have a strong tendency to change food type during feeding bouts. They suggested that the choice of food is predominately controlled by learned associations between the foods and their hedonic properties rather than by immediate feedback from metabolic receptors, which would not have time to be significantly influenced by the food eaten earlier in the meal.

On the basis of the results presented, it seems that the negative effects of supplementation of diet in pellet form to broiler chicks, especially in the first week of their life, on feed intake may be directly related to the larger particle size being a physical barrier to either consumption or digestion.

An additional quality of the feed that may have an impact of feed consumption is flavour. This is investigated in the next section as a viable economic opportunity to manipulate domesticated poultry feeding preferences.

Chapter 10: The Effect of Supplementation of Garlic Powder as Flavour to the Starter Crumb Diet on The Feeding Preference of Male Broiler Chicks

10.1 Introduction

A majority of poultry producers and some researchers have assumed that birds have a limited sense of taste and that flavour has no role to play in poultry feeding. However, examination of the literature suggests that, while far from being conclusive, there is compelling evidence to suggest that birds have a sense of taste (Appleby *et al.*, 2004). The question at issue is whether, for purposes of poultry production, it makes a difference (Damron, 2003).

Lindenmaier and Kare (1959) found 8 taste buds in a day old chick and 24 in a 3 month old cockerel). The positions of the buds identified were only on the base of the tongue and floor of the pharynx. Yet, because the evidence indicated that taste mechanisms are quite complex in birds, the suggestion was that other taste receptors might exist. Closer examination of the buds showed a morphological similarity to those found in mammals. Due to this similarity and the difference in numbers of buds found on average in birds versus mammals (around 24 for birds, 9,000 for humans, and 25,000 for a cow), the extent of taste ability in birds was still questioned (El Boushy and Kennedy, 1987; and see Damron, 2003), though other estimates of the number of taste buds in poultry were higher (Appleby *et al.*, 2004, reported 350–500). In any event, poultry can differentiate certain tastes and flavours (Nesheim *et al.*, 1979).

The situation is further complicated by consideration of olfaction.

Kare (1965) noted that birds do not have an acute sense of smell. Against this, birds have a functioning olfactory system (Tucker, 1965; Stattelman *et al.*, 1975), and the removal of the olfactory tissues has been shown to increase food intake in chickens (Robinzon *et al.*, 1977). Moreover, contrary to Kare's assertion, olfaction is highly important to some species—albatrosses, for example, may detect meat (by smell) from a distance of 20 miles (Miller, as cited in Appleby *et al.*, 2004). Olfaction might also be important for migratory pigeons, as supplementary means of navigation (Appleby *et al.*, 2004). Domestic fowl can be operantly conditioned to distinguish certain scents, oil of citron, for instance (Jones and Gentle, as cited in Appleby *et al.*, 2004).

Given that some taste (and smell) ability does exist in poultry, the use of flavourings offers potential management solutions for a number of problems. For example, flavouring could be used to depress or prevent the phenomenon of "starveouts" in order to keep birds feeding when they are stressed (e.g., diseased or overheated). Use of flavours to minimize overheating stress could be beneficial in countries with hot climates. Flavouring may also be used to improve the palatability of certain food ingredients that tend to decrease feeding (such as blood meal, fish soluble, and fermentation by-products or dusty ground grains like wheat and milo).

Facilitating affective responses to odours is a key role of olfaction (Garcia *et al.*, 1974; Brett *et al.*, 1976). According to Gentle (1971), colour, taste, smell, and other physical properties of food strongly influence food intake and can be significant behavioural modifiers where feeding choices are available. Addition of feed additives, flavours, and colours in poultry feed does affect diet selection

(Leeson and Summers, 1985; Balog and Millar, 1989). However, the effects appear to involve short-term learning associations only. For example, Balog and Millar (1989) showed that birds have a preference for a basal feed when flavours were used to differentiate a range of feeds: however, these preferences disappeared when feeding troughs were moved every second day.

A number of animal studies have illustrated the potential role of garlic a hypolipidemic, hypotensive, hypoglycemic, hypothrombotic, and hypoatherogenic (Bordia *et al.*, 1975; Shoetan *et al.*, 1984); in fact, a garlic paste (3.8%), solvent fractions, or garlic oil of similar equivalence concentrations, has been shown to reduce serum cholesterol by 18 and 23% in broilers and 12-week-old-Leghorn pullets, respectively, over a 4 week period (Qureshi *et al.*, 1983b). Studies in which garlic was fed to 5-week-old male broilers for 3 weeks and in vitro studies with chicken hepatocytes exposed to polar fractions of garlic powder (garlic equivalent to 1, 2, 4, 6 and 8.0% fresh garlic paste) illustrated a dose-dependent inhibition of hepatic β-hydroxy-β-methylglutaryl coenzyme A (HMGCoA) reductase, cholesterol 7α-hydroxylase, and fatty acid synthetase (Qureshi *et al.*, 1983a). In addition, a reduction in egg yolk cholesterol levels is observed when laying hens are fed 1 or 3% garlic powder for 3 wk (Sharma *et al.*, 1979). In a similar cholesterol study, Sklan *et al.* (1992) reported decreased hepatic cholesterol concentrations in chickens fed 2% garlic for 14 days. Contrary to these results, Birrenkott *et al.* (2000) observed no significant effect on yolk and serum cholesterol concentrations when laying hens were fed 3% garlic powder for 8 months. Similar conclusions were drawn by Reddy *et al.* (1991), who reported that neither egg production, egg mass, body weight, feed intake, nor feed efficiency were affected during feeding of Babcock B-300 strain birds with 0.02% garlic oil over a 8 week period. However, in a study to characterize the hypocholesterolemic effects of high levels of sun-dried garlic paste in the diets of different genetic strains of laying hens, Han and Lee (1992) concluded that responses to garlic were highly strain dependent.

As both a spice and medicine, garlic (*Allium sativum*) is widely grown and used around the world. It has been studied extensively for its pharmacological properties and has been found to lower serum and liver cholesterol (Qureshi *et al.*, 1983a; Chowdhury *et al.*, 2002) and inhibit platelet aggregation (Apitz-Castro *et al.*, 1983). Even in birds, Tollba and Hassan (2003) have reported that garlic as natural feed additive raised broiler growth rates, produced higher feed conversion ratios (FCR), and decreased mortality rates. These results are supported by Demir *et al.* (2003), who reported reduced crypt depth in the ileum of broilers administered garlic via the diet.

10.2 Experiment 10

Given the plausibility that taste and smell can affect birds' feeding behaviour, and given the plausibility that garlic has beneficial effects on birds, the experiment aimed to test chicks' feeding preferences as regards flavour, and to do so by using garlic as a flavour enhancer. Thus the experiment investigated whether garlic powder supplements in the diets of broiler chicks affects their feeding preferences.

10.2.1 Materials and Methods

Materials and methods were as described for experiment 6.

10.2.1.1 Treatments

Chicks were first familiarised with the diets by sequentially presenting the alternative diets over a 2-day period to allow them to become accustomed to the sensory properties of each diet. Two treatments with 3 replicates each were used in this experiment: T1 (starter crumbs diet, 8.0% fat, on the 1st day followed by starter crumbs diet + powder garlic, 8.0% fat, on the 2nd day) and T2 (starter crumbs diet + powder garlic, 8.0% fat, on the 1st day followed by starter crumbs diet, 8.0% fat, on the 2nd day. Chicks were then offered a choice between starter crumbs diet and starter crumbs diet + powder garlic for 5 days after 2h fasting. See Plate 10.1. The powder garlic source was commercial one. There were 3 replicates with 10 birds each. See Box 10.1 for a summary of the treatments.

Plate 10. 1. Feeders offering free-choice flavoured (garlic) and non-flavoured food.

Box 10. 1. Treatments: feeding procedure; experiment 10.

	Treatments	
Day	T1	T2
8	HF starter crumb diet. No garlic	HF starter crumb diet. Garlic
9	HF starter crumb diet. Garlic	HF starter crumb diet. No garlic
10	2h fast followed by HF starter crumb diet. Garlic and no garlic. Free-choice	2h fast followed by HF starter crumb diet. Garlic and no garlic. Free-choice
11–14	HF starter crumb diet. Garlic and no garlic. Free-choice	HF starter crumb diet. Garlic and no garlic. Free-choice

HF: high fat

10.2.1.2 Statistical analysis

The dependent variables and data analysis methods were the same as for experiment 7, save that the food quality of interest was flavour (garlic or no garlic).

10.2.2 Results

10.2.2.1 The performance of broiler chicks

The results of the effect of treatment on total feed intake, final body weight, body gain, and feed conversion ratio are presented in Table 10.1. No significant differences between treatments were detected for total feed intakes (g/bird) after 7 days (T1: 437g/bird and T2: 438g/bird). No significant differences were observed in final body weight, body gain, and feed conversion ratios between the two treatments.

Table 10. 1. Total feed intake, final body weight, weight gain and feed conversion ratios of birds in the two treatments after 7 days.

Parameters	T1	T2	SE
Total feed intake (g/bird)	437	438	± 53.4
Final body weight (g/bird)	518	501	± 3.2
Final weight gain (g/bird)	338	342	± 2.9
Feed conversion ratio (g/g)	1.2	1.1	± 0.04

($p < .05$)

A significant difference ($p < .05$) was detected within T1 during the free-choice period. That is to say that a significant decline in feed intake on flavoured feed was recorded during the free-choice period when chicks were initially fed on unflavoured diets on the first day of the trial (44 versus 27g/bird/d). No significant differences were detected within T2 (41 vs. 30g/bird/d) or between treatments. See Table 10.2.

Table 10. 2. Mean feed intake of the chicks fed on unflavoured and flavoured diet during the free-choice period (5 days).

Diet Flavouring	T1	T2	SE
	(g/bird/d)		
Unflavoured diet	44^{a}	41^{a}	± 3.0
Flavoured diet	27^{b}	30^{ab}	± 3.0

[a,b] Mean values not sharing a common superscript letter are significantly different ($p < .05$)

There was a significant difference ($p < .05$) between the weights of unflavoured and flavoured diets eaten during the first hour and 24h into the free-choice period when the initial diet was unflavoured (T1) but not when the initial diet was flavoured (T2). See Table 10.3. No statistical differences were detected during the first hour of the free-choice period between the treatments, but the flavoured diet feed intake was lower ($p < .05$) if chicks were initially fed unflavoured diet at the beginning of the trial (T1) compared with flavoured diet (T2) (16g/bird versus 26g/bird respectively) after 24h.

Table 10. 3. Feed intake of the chicks fed on unflavoured and flavoured diet after the first hour and 24h into the free-choice period.

	1h			24h		
Diet Flavouring	T1	T2	SE	T1	T2	SE
			(g/bird)			
Unflavoured diet	5^{a}	2^{ab}	± 0.8	44^{a}	31^{a}	± 6.6
Flavoured diet	1^{b}	2^{ab}	± 0.8	16^{b}	26^{a}	± 6.6

^{a,b} Mean values not sharing a common superscript letter are significantly different (p < .05)

10.2.2.2 The behaviour of broiler chicks

A summary of feeding, drinking and pecking behavioural results are presented in Table 10.4. Statistical analysis revealed no differences between the two treatments.

Table 10. 4. Mean feeding, drinking and pecking behavioural responses over 6 days observation.

Parameters	T1	T2	SE
Feeding (no/b/h)	10	16	± 4.8
Drinking (no/b/h)	6	8	± 2.3
Pecking (no/b/h)	10	10	± 3.4

(p < .05); no: number; b: bird; h: hour

Statistical analysis of the feeding behaviour on the unflavoured and flavoured diets during the free-choice period showed no differences within a treatment or between the two treatments, Table 10.5.

Table 10. 5 Mean feeding behaviour on the two diets during the free-choice period (5 days).

Diet Flavouring	T1	T2	SE
	(no/b/h)		
Unflavoured diet	13	9	± 4.3
Flavoured diet	4	9	± 4.3

($p < .05$); no: number; b:bird; h: hour

10.2.3 Discussion

The purpose of this experiment was to examine the effect of flavour on broiler chicks' feeding preferences. This study, like most others, has attempted to determine if broiler chicks can detect garlic flavour, and if they can, what responses they show. Levels of garlic flavour used in this study were excessive in an attempt to make the chicks more likely to sense its presence. The results indicated that when broiler chicks were offered a choice between unflavoured and flavoured diets there were significant differences ($p < .05$) in feed intake on the basis of flavour only when fed using the T1 regime, while feed intake in T2 birds was not significantly different between unflavoured and flavoured diets. The difference was shown by the preference for unflavoured diet compared with garlic flavoured diet in T1 birds. The broiler chicks perceived something different in the flavoured diets and ate less of this diet. The likes and dislikes of broiler chicks in this treatment agree with the reviews offered by El Boushy and Kennedy (1998) and Balog and Millar (1989). Garlic is very rich in aromatic oils, which enhances digestion and also potentially positively influences olfactory detection of the presence of garlic in the feed. The strong antioxidative effect of garlic seems especially important, as happens today, when poultry feeds are increasingly supplemented with fat. The strong smell of aromatic oils may penetrate into feed ingredients; this could have improved their flavour, thus improving feed intake rates.

One interesting observation in this experiment was that the broiler chicks ate less diet with garlic powder added at a concentration of 3% by feed volume. The proportional quantities of garlic powder added may have partly been responsible for the depression of feeding in chicks in T1. It also appears that the garlic had some depressive effects in T2, but the results were not significant. Since there was no nutritional positive reinforcement to be associated with the detection of the garlic by the young birds, one possible explanation for the depression of food intake could be an inherent aversion to newly encountered strong tasting of smelling foods. It is also possible, of course, that the level of garlic used was too high—maybe chicks like a little garlic but not a lot of it; indeed, it is possible that large amounts of garlic are harmful but small amounts beneficial (almost all plants produce toxins in order to protect themselves from pests; research on humans and rodents suggests such toxins may have beneficial effects when ingested by vertebrates in small doses—they are anti-oxidants—but are carcinogenic when ingested in large doses—see, e.g., Ames and Gold, 1990, 1997; Ames, 2006; Avery 1995). In terms of commercial poultry production, this is a subject for future research: determining the optimal level, if any, of garlic flavouring. Note here that the results of the present experiment suggest that chicks do respond to food flavour.

The change in the fat content of the feed has been considered within this study together with other physical attributes. However, one potential option that has not been previously considered is the separate presentation to birds of a source of fat that can be independently taken by the birds. This has many potential benefits since the exact composition of the core feed need not necessarily be changed if birds can obtain the fat they need from a source given separately to the main feed. This is the focus of the next chapter.

Chapter 11: The Effect of Supplemental Fat Offered Separately on the Feeding Preference of Chicks Given a Free Choice Selection Regime

11.1 Introduction

The numerous benefits of supplementing fat in poultry diets have been extensively documented. In a very early study, Biely and March (1957) noted that supplemental tallow in poultry diets improved utilization of nutrients and led to increased growth rates. As well as having a direct energy contribution, fat has also been reported to enhance feeding efficiency because of an "extra caloric" effect. This effect has been observed in both young and adult birds (Vermeersch and Vanschoubroek, 1968).

The consensus is that digestion and absorption of fat is initially inefficient in young poultry but that efficiency rapidly improves with age (Renner and Hill, 1960; Young, 1961; Carew *et al.*, 1972; Gomez and Polin, 1974; Polin and Hussein, 1982). The age dependent effects are most noticeable when the source of fat is relatively saturated, which is often attributed to the reduced digestion and absorption of C16:0 and C18:0 compounds. An improvement in absorption efficiencies with age is at least partially a result of increased bile salt production and higher intestinal lipase activity (Krogdahl and Sell, 1985; Krogdahl and Sell, 1989). Yet it appears that lipid digestive efficiency of young birds can only be partially enhanced by including additional bile salts (Gomez and Polin, 1976; Katongole and March, 1980; Polin *et al.*, 1980; Polin and Hussein, 1982) or lipase (Polin *et al.*, 1980).

In contrast, the observed digestion and absorption of polyunsaturated fatty acids is much higher than saturated fats (85%) in young chicks (Sklan *et al.*, 1973; Noy and Sklan, 1995) and diets containing medium-chain length triglycerides have even higher utilization rates. This was demonstrated by Ketels and DeGroote (1988) who reported that 2-week-old chicks utilized upward of 90% of the fatty acids from supplied coconut oil, which has a high proportion of medium-chain fatty acids (44% C12:0). Use of synthetic sources of medium-chain triglycerides (100% C8:0) also appears to be responsible for overall improvements in growth rates of chicks during the initial couple of weeks after they hatch (Mabayo *et al.*, 1992). The explanations of why medium-chain fatty acids (C6:0 to C12:0) are more easily digested and absorbed compared to long-chain fatty acids, are based upon both their relative size and solubility. In addition, it is known that medium-chain fatty acids are more easily absorbed in the presence of low concentrations of bile salts and pancreatic lipase (Bach and Babayan, 1982). The vast majority of research into the utilization of fat with increasing bird age has focused on birds older than 2 weeks of age. There are few studies that have examined fat utilization by very young chicks (Carew *et al.*, 1972; Noy and Sklan, 1995, 2002; Sklan, 2003).

11.2 Experiment 11

The objective of the experiment was to detect if very young broiler chicks could balance their needs from supplemental fat sources when the fat is offered as free-choice in separate troughs beside the control diet. The focus was on feed consumption and body weight changes between the three treatments.

11.2.1 Materials and Methods

Materials and methods were as described for experiment 6.

11.2.1.1 Treatments

Three treatments were used in this experiment: T1 (standard commercial starter crumbs diet + supplemental fat), T2 (standard commercial starter crumbs diet on the 1st day followed by standard commercial starter crumbs diet + supplemental fat on the rest of remaining days), and T3 (standard commercial starter crumbs diet) for 7 days. There were 2 replicates with 10 birds each. See Plate 11.1.See Box 11.1 for a summary of the treatments.

Plate 11. 1. Feeders offering free-choice supplemental fats.

Box 11. 1. Treatments: feeding procedure; experiment 11.

	Treatments		
Day	T1	T2	T3
1	Standard commercial starter crumb diet + supplemental fat	Standard commercial starter crumb diet.	Standard commercial starter crumb diet
2–7	Standard commercial starter crumb diet + supplemental fat	Standard commercial starter crumb diet + supplemental fat	Standard commercial starter crumb diet

The ingredients of the fat supplement (fat ball, Commercial one) were cereals, oil and fat, seeds, minerals, and nuts.

11.2.1.2 Statistical analysis

The dependent variables and data analysis methods were the same as for the previous experiment, save that the factors of interest were physical (body weight etc.) and did not involve free-choice. The independent variable was treatment (T1, T2, and T3; between measures).

11.2.2 Results

11.2.2.1 The performance of broiler chicks

The results of the effect of treatment on feed intake, final body weight, body weight gain, and feed conversion ratio are presented in Table 11.1. The broiler chicks fed on standard commercial starter crumbs diet + supplemental fat ate less food (but not significantly) than chicks in the other treatments (127 vs. 133 and 130g/bird). There was a correspondingly marginal increase in total supplemental fat intake in the same treatment.

Table 11. 1. Total feed intake, final body weight, weight gain and feed conversion ratio.

Parameters	T1	T2	T3	SE
Total feed intake (g/bird)	127	133	130	± 3.1
Total fat supplemental intake (g/bird)	6	4	-	± 0.8
Final body weight (g/bird)	141	145	139	± 3.8
Total weight gain (g/bird)	98	101	96	± 3.8
Feed conversion ratio (g/g)	1.3	1.3	1.4	± 0.07

($p < .05$)

11.2.2.2 The behaviour of broiler chicks

A summary of results relating to feeding, drinking and pecking behaviours is presented in Table 11.2. Statistical analysis showed no differences between the three treatments.

Table 11. 2. Mean of feeding, drinking and pecking behaviours during 7 days.

Parameters	T1	T2	T3	SE
Feeding (no/b/h)	8	9	10	± 3.6
Drinking (no/b/h)	8	8	9	± 4.0
Pecking (no/b/h)	9	11	11	± 4.7

($p < .05$); no: number; b: bird; h: hour

11.2.3 Discussion

The current experiments failed to demonstrate that chicks significantly ($p < .05$) consumed supplemental fat, although trends suggested that they may be able to reduce total feed intake by compensating with added fat consumption. Given the very small changes in both total food consumed and supplementary fats, it is conceivable that replication number was insufficient to maintain a sufficiently high enough statistical power to detect any significant trends. It is known that there is a high energy dependence over the first few day after hatching from fat that is available in the yolk sac of young birds (Freeman, 1965; Broom, 1968; Rogers, 1989; Forbes 1995; Appleby *et al.*,2004).

Regardless of the results from this experiment there still remain questions regarding fat levels in diets and bird performance specifically in relation to whether performance metrics can be improved through diet manipulation over very long developmental time periods. In the following chapter performance metrics are examined when birds are offered fat-rich diets that differ in protein content. The experiments are based upon results from previous studies reported within the present study.

Chapter 12: The Effects of Different Levels of Fat and Protein on Broiler Chick Preferences

12.1 Introduction

A number of studies have reported that chickens show marked preferences for a particular diet in a free-choice feeding regime, such that the diet selected, by the chicks, will provide a mixture that best matches their metabolic requirements (Fuller, 2004). Rose and Kyriazakis, (1991) stated that birds are able to choose between combinations of two foods that reflect their needs. In addition, a diet selection is affected by preference, experience, and possible social transmission of feeding behaviour (Chapple and Lynch, 1986; but see Whiten *et al.*, 2004).

Noy and Sklan (2002) examined the nutritional requirements of chicks during the first week post-hatch, but in general a free-choice diet in the first week post-hatch should take into account the contribution of the utilization of fats stored in the young birds' yolk sac during the first few days after hatching (Forbes 1995, Appleby *et al.*, 2004) and that offering a high fat level diet alone may be insufficient for optimal development. Furthermore the result of experiment 1 suggests that some factor(s) other than fat content level are affecting diet choice by chicks after around 7 days of age. For these reasons, two experiments were conducted: the first in order to investigate the preferences of broiler chicks for diets differing in fat (4.6 and 8%) and protein (24 and 26%) levels from 7 to 14 day of age during a free-choice feeding regime, and the second to determine whether it is possible to maintain higher consumption rates on high fat diets after day 7 by adding additional protein to the high fat diet.

12.2 Experiment 12

12.2.1 Materials and Methods

Materials and methods were as described for experiment 2, except that the only parameter recorded was feed intake.

12.2.1.1 Treatment

In this experiment twenty male broiler chicks were given a high fat level diet (8.0%) during days 1–7 followed by a choice of three diets over a subsequent 7 day period. The diets used were different in fat and protein levels: diet1 (4.6%fat + 24% protein), diet2 (8.0%fat + 26% protein), and diet3 (4.6%fat + 26% protein). All diets were provided *ad libitum*. The physical properties of the feed crumbs were standard across all 3 types of diet, as shown in Box 12.1.

Box 12. 1 Treatments: feeding procedure; experiment 12.

	Treatment
Day	Free choice
1–7	HF starter crumb diet
8–14	Diet 1(4.6%fat + 24% protein), diet 2(8.0%fat + 26% protein), and diet 3(4.6%fat + 26% protein) starter crumb diet

HF: high fat

12.2.1.2 Measurements

12.2.1.3.1 Feed intake

Group feed intake was recorded daily throughout the experimental period.

12.2.1.3 Statistical analysis

The dependent variables and data analysis methods were the same as for the previous experiment. The independent variables were diet (diet 1, diet 2, and diet 3; between measures).

12.2.2 Results

12.3.2.1 Feed intake

Feed consumption results are presented in Table 12.1. Results show feed intake of diet 1 (4.6%fat + 24% protein) on day 8 was 20g and this increased steadily until day 14. The pattern of intake for diet 2 (8.0%fat + 26% protein) is similar to that of T1 in the first two days; it periodically decreased and increased in the remaining days. However, from the start the intake of diet 3 (4.6%fat + 26% protein) was lower than that of diet 1 and diet 2, but not siginficant except on day 10 where a significant difference ($p < .05$) was recorded between diet 1 and diet 3 where the mean of diet 1 was recorded as 26g compared to 15g for diet 3.

Table 12. 1. Daily feed intake of the three diets consumed by broiler chicks.

Diet	Day						
	8	9	10	11	12	13	14
	Feed Intake (g/day)						
Diet 1	20	21	26 [a]	29	29	34	35
Diet 2	20	21	18 [ab]	21	31	27	33
Diet 3	11	17	15 [b]	18	17	20	34
SE	± 5.5	± 9.7	± 2.4	± 8.0	± 3.5	± 5.4	± 4.0

[a,b] Mean values not sharing a common superscript letter are significantly different ($p < .05$)

When overall mean intake was calculated between days 8 to 14, a significant difference ($p < .05$) was recorded between diets 1 and 3: where the mean of diet 1 was 28g compared to 19g for diet 3. See Table 12. 2.

Table 12. 2. Mean feed intake of three treatments consumed by broiler chicks from day 8 to day 14.

Diet	Mean (g/bird)
Diet1	28 [a]
Diet 2	25 [ab]
Diet 3	19 [b]
SE	± 7.5

[a,b] Mean values not sharing a common superscript letter are significantly different ($p < .05$)

12.2.3 Discussion

Feed consumption during the second week post-hatch was affected by the diet regime treatments, with intake being lower as percentage protein increased in the diet.

The results of this experiment showed that the birds consumed significantly ($p < .05$) more from diet 1 (4.6% fat + 24% protein diet) and diet 2 (8.0% fat + 26% protein diet) compared to diet 3 (4.6% fat + 26% protein diet) during the second week.

In conclusion, the results of this experiment suggest that diets containing high protein percentages (diet 3) lead to lower feeding consumption preferences. However, this reduced preference for higher protein foods can be compensated for to some extent by increasing the fat levels of the feed. Overall, the results from this study, namely decreased feed intake with increasing protein content, are consistent with those reported in previous studies in older birds (Parsons and Baker, 1982; Smith and Pesti, 1998) and in younger birds (Noy and Sklan, 2002)

These results suggest that long-term developmental performance is likely to be significantly affected by diet composition in relation to fat and protein content of feeds fed to very young chicks. The subsequent experiment draws upon the results from the previous experiment to consider whether a key target metric like time to reach slaughter weight can be modified through manipulation of diet of very young birds.

12.3 Experiment 13: The Effect of Different Levels of Fat and Protein on Broiler Chick Performances

This experiment investigated whether broiler chick performance, namely time to reach target market weight, could be enhanced in conjunction with decreasing feed consumption by increasing protein content in high fat diets during the second week post-hatching period.

12.3.1 Materials and Methods

Materials and methods were as described for experiment 2, except that different behaviours were recorded. The behaviours recorded comprised feeding and drinking only. There were 4 replicates with 10 birds each.

12.3.1.1 Diets used

Crumb starter diets having two different fat and protein levels (4.6% and 24% as in standard commercial starter diet, 8.0% and 26% and 4.6% and 26%, respectively), grower and finisher diets were also used in this experiment.

12.3.1.2 Treatment

One hundred and twenty, 1-day-old male broiler chicks were fed on either low fat (4.6%) starter diet (T1) or high fat (8.0%) starter, diet (T2 and T 3) during the 1^{st} week followed by 4.6% fat+ 24% protein (T1), 8.0% fat + 26% protein diet

(T2) and 4.6% fat diet+ 26% protein diet (T3) during the 2nd week and then grower and finisher diets in the remaining weeks as illustrated in Box 12.2.

Box 12. 2 Treatments: feeding procedure; experiment 13.

	Treatments		
Day	T1	T2	T3
1–7	LF starter crumb diet	HF starter crumb diet	HF starter crumb diet
8–14	4.6% fat+ 24% protein starter crumb diet	8.0% fat + 26% protein starter crumb diet	4.6% fat diet+ 26% protein starter crumb diet
15–28	Grower diet	Grower diet	Grower diet
29–35	Finisher diet	Finisher diet	Finisher diet

HF: high fat; LF: low fat

12.3.1.3 Statistical analysis

The dependent variables and data analysis methods were the same as for the previous experiment. The independent variable was treatment (T1, T2, and T3; between measures).

12.3.2 Results

12.3.2.1 The performance of broiler chickens

Statistical analysis of the weekly feed intake, body weight, weight gain and feed conversion ratio results showed no differences between the three treatments (Table 12.3).

Table 12. 3. Mean weekly feed intake, body weight, weight gain and feed conversion ratio.

	Week				
Treatment	1	2	3	4	5
		Feed intake (g/bird/week)			
T1	158	440	783	1076	1340
T2	153	427	772	1067	1314
T3	154	444	787	1069	1310
SE	± 3.9	± 6.4	±17.0	± 40.2	± 44.0
		Body weight (g/bird/week)			
T1	206	589	1169	1873	2630
T2	201	589	1168	1882	2631
T3	204	596	1175	1903	2656
SE	± 5.6	± 12.6	±24.3	± 35.1	± 49.4
		Weight gain (g/bird/week)			
T1	163	383	580	705	757
T2	158	388	579	714	750
T3	161	392	579	728	753
SE	± 4.7	± 8.8	±18.3	± 28.8	± 55.5
		Feed conversion ratio (g /g)			
T1	0.97	1.2	1.4	1.5	1.8
T2	0.97	1.1	1.3	1.5	1.8
T3	0.96	1.1	1.4	1.5	1.7
SE	± 0.01	± 0.02	± 0.03	± 0.07	± 0.16

($p < .05$)

There were no significant differences recorded between the three treatments in terms of total feed intake, final body weight, weight gain, and feed conversion ratio. See Table 12.4.

Table 12. 4. Total feed intake, final body weight, weight gain and feed conversion ratio of male broilers during whole period (35 days).

Parameters	T1	T2	T3	SE
Total feed intake (g/bird)	3798	3732	3764	± 81.3
Final body weight (g/bird)	2630	2631	2656	± 49.4
Final weight gain (g/bird)	2586	2588	2613	± 49.6
Feed conversion ratio (g/g)	1.8	1.8	1.7	± 0.16

($p < .05$)

The results showed that the three different treatments did not have any effect on carcass composition or weight of body components of the broiler chickens (Table 12.5).

Table 12. 5. Carcass composition and mean weight of body components.

Parameters	T1	T2	T3	SE
	Carcass Composition (%)			
Dry matter	32	33	34	± 2.2
Moisture	68	67	66	± 2.2
Fat	38	38	38	± 1.2
Protein	57	57	58	± 1.2
	Body Components (g/bird)			
Left half	900	999	991	± 81.5
Flesh	621	687	692	± 79.8
Skin	91	99	98	± 1.81
Bone	188	198	197	± 12.8
Dressing Percentage	73	72	72	± 1.04

($p < .05$)

12.3.2.2 The behaviour of broiler chickens

A summary of the results for feeding, drinking behaviours is presented in Table 12.6. Statistical analysis of the results showed no differences detected between the 3 treatments.

Table 12. 6. Mean of feeding and drinking behaviours during the first 14 days experiment.

Parameters	T1	T2	T3	SE
Feeding(no/b/h)	6	7	7	± 3.1
Drinking(no/b/h)	4	3	4	± 2.3

($p < .05$); no: number; b: bird; h: hour

12.3.3 Discussion

This experiment examined the effect of different levels of fat and protein on performance of the chicks during second week post-hatch. It found no significant differences. This is in contrast to other work. Noy and Sklan, (1998), for instance, found that early modification of feeding regime post-hatch enhances growth; different levels of fat and protein in chicks' diet affects the birds' performance and can effect a more rapid achievement of target market weights. The experiment has shown that feed intake, body weight, body weight gain feed conversion ratio, dressing percentage, carcass composition, body components, and behavioural parameters (feeding and drinking) did not show any significant difference when early diet content was manipulated in terms of protein to fat ratios.

Although feed intake was higher in chicks that consumed the control diet (T1) when compared to chicks consuming the 8.0%fat + 26% protein diet, the result was not significant. One possible explanation is that the higher dietary energy density and higher protein content in the diets depressed the feed intake in this experiment. This result accords with that of Plavnik *et al.*, (1997), who found decreased feed intake with increasing energy density in older birds.

Yet again, although body weight and body weight gain appeared to be influenced by protein level, which increased as the dietary protein level increased, the results were not significant. Again, this result is in disagreement with those of Noy and Sklan (2002), who reported that increased level of protein was associated with decreased body weight gain.

Carcass composition, body components, and behavioural parameters (feeding and drinking) in all treatments were not altered by the different diets in the first two weeks post-hatching. Overall, it thus appears that feeding diets with high fat level (8%) for 1st week in T2 and T3, feeding diet with high fat level (8%) and high protein percent (26%) in T2 and feeding diet with high protein percent

(26%) in T3 for the 2nd week had no appreciable effect on performances of chickens, particularly with respect to speed to reach target market weights.

The experiments are based upon results from previous research reported within this study. There remain questions regarding fat levels in diets and bird performance, specifically in relation to whether performance metrics can be improved through diet manipulation over very long developmental time periods. In the following chapter performance metrics are examined when birds are offered diets that differ in fat content (1 and 3%) higher than 1994 NRC specifications in all periods

Chapter 13: Broiler Performance and Fat Content of Carcasses

13.1 Introduction

As discussed, the majority of poultry diets contain energy-rich fats. Indeed, vegetable oils and animal fats are widely known as a source of this energy-rich dietary source, and this is evidenced by the fact that they are added frequently to poultry diets. Soya oil is one of the vegetable oils most commonly used; it can be entirely digested by broiler chickens, since it has high levels of unsaturated acids compared with some animal fats (e.g., tallow, which has higher saturated fatty acid levels) and are not well utilised by young broilers (Leeson and Atteh, 1995). Thus, research on poultry diets has reported that a mixture of unsaturated and saturated fatty acids would be suitable for broilers diets (Sanz *et al.*, 2000). This mixture provides less abdominal fat because it has polyunsaturated fatty acids, such as linoleic and linolenic acids. These kinds of fatty acids must be added into the diet because their presence is vital to humans and animals (Pinchasov and Nir, 1992). However, humans are affected by these fatty acids indirectly through eating broiler meat. Feeding fowl with certain fatty acids impacts on the levels of essential fatty acids in their meat (Scaife *et a*l., 1994). Consequently, this is of great concern to both poultry farmers and the final consumers of poultry, namely ourselves.

Fat quality has to be taken into account when fat supplementation is added into broiler diets because dietary fatty acids are intermingled with small change into the body fat (Scaife *et al.*, 1994). Humans and animals are influenced positively by a number of benefits that particular fatty acids offer; these include dietary omega-3, which decreases the risk of heart diseases and decreases cholesterol concentrations (Phetteplace. and Watkins, 1990; Zollitsch, *et al.*, 1996; Lopez-Ferrer *et al.*, 1999; Simopoulos, 2000). Although the majority of experiments and studies have been conducted with two weeks of age or older, a few reports have been conducted on the utilisation of fat with chicks (Carew *et al.*, 1972; Turner *et al.*, 1999; Noy and Sklan, 1995, 2002; Sklan, 2003; Azman *et al.*, 2004; Freitas *et al.*, 2005; Vieira *et al.*, 2006).

Furthermore, a supplementation of fat at 8.0% in starter crumbs diet (experiments 1 and 3), starter crumbs and pellet diets (experiment 4), and a 2% fat higher than NRC (1994) specifications in all periods (experiment 6) have not been shown to affect, negatively or positively, broiler performance. Therefore, the objectives of the two experiments reported herein were to investigate the effect of increasing fat levels (3 and 1 % respectively higher than 1994 NRC specifications) during different periods on carcass composition and performance of broiler chicken grown to five weeks old.

13.2 Experiment 14. Broiler Performance and Carcass Composition as Affected by Supplemental Fat at Different Periods. I: 3% Higher than Recommended at Different Periods.

13.2.1 Materials and Methods

Materials and methods were as described for experiment 13.

13.2.1.1 Treatment

In this experiment, a total of 120 one-day-old broiler chicks were randomly assigned to six dietary treatments groups of 20 birds each. Starter crumb and pellet, grower, and finisher diets had two different fat levels (one as standard commercial diet and the other 3 % fat higher than 1994 NRC specifications). The fats in the diets came from soya oil. There were 2 replicates with 10 birds each. The treatment groups are described in Box 13.1.

Box 13. 1. Treatments: feeding procedure; experiment 14.

	Treatments					
Week	T1	T2	T3	T4	T5	T6
1	S crumb diet. . 4.6% fat	S crumb diet. 7.6% fat	S crumb diet. 7.6% fat	S crumb diet. 7.6% fat	S crumb diet. 7.6% fat	S crumb diet. 7.6% fat
2	S pellet diet. 6.7% fat	S pellet diet. 6.7% fat	S pellet diet. 9.7% fat	S pellet diet. 9.7% fat	S pellet diet. 9.7% fat	S pellet diet. 9.7% fat
3	Grower diet. 7.7% fat	Grower diet. 7.7% fat	Grower diet. 7.7% fat	Grower diet. 10.7% fat	Grower diet. 10.7% fat	Grower diet. 10.7% fat
4	Grower diet. 7.7% fat	Grower diet. 7.7% fat	Grower diet. 7.7% fat	Grower diet. 7.7% fat	Grower diet. 10.7% fat	Grower diet. 10.7% fat
5	Finisher diet. 9.1% fat	Finisher diet. 9.1% fat	Finisher diet. 9.1% fat	Finisher diet. 9.1% fat	Finisher diet. 9.1% fat	Finisher diet. 12.1% fat

T1: control groups; S: starter

All diets were provided *ad libitum*. The physical properties of the diets were standard.

13.2.1.2 Statistical analysis

The dependent variables and data analysis methods were the same as for the previous experiment. The independent variable was treatment (T1–T6); between measures).

13.2.2 Results

13.2.2.1 The performance of broiler chickens

Statistical analysis of the weekly feed intake, body weight, weight gain and feed conversion ratio results showed no differences between the six treatments (Table 13.1).

Table 13. 1. Mean weekly feed intake, body weight, weight gain and feed conversion ratio.

Treatment	Week 1	2	3	4	5
		Feed intake (g/bird/week)			
T1	156	447	803	935	1292
T2	140	438	774	1059	1266
T3	146	428	755	913	1293
T4	147	409	677	991	1221
T5	141	414	704	968	1220
T6	148	412	742	1002	1250
SE	± 9.6	± 30.1	± 42.5	± 151.9	± 38.6
		Body weight (g/bird/week)			
T1	204	585	1178	1926	2645
T2	180	542	1068	1814	2531
T3	194	546	1117	1748	2577
T4	193	532	1038	1746	2492
T5	189	534	1074	1741	2534
T6	195	539	1097	1779	2547
SE	± 12.6	± 31.9	±70.6	± 72.9	± 53.0
		Weight gain (g/bird/week)			
T1	157	382	593	748	719
T2	134	362	526	746	717
T3	148	352	571	732	729
T4	147	339	506	708	746
T5	142	345	541	667	793
T6	148	344	559	682	769
SE	± 12.2	± 21.2	±43.1	± 21.8	± 24.0
		Feed conversion ratio (g/g)			
T1	0.99	1.2	1.4	1.3	1.8
T2	1.05	1.2	1.5	1.4	1.8
T3	1.00	1.2	1.3	1.3	1.8
T4	1.00	1.2	1.3	1.4	1.6
T5	1.00	1.2	1.3	1.5	1.5
T6	1.00	1.2	1.3	1.5	1.6
SE	± 0.03	± 0.05	± 0.08	± 0.21	± 0.07

($p < .05$)

There were no significant differences between the six treatments in terms of total feed intake, final body weight, weight gain, and feed conversion ratio. See Table 13.2.

Table 13. 2. Total feed intake, final body weight, weight gain and feed conversion ratio of male broilers during whole period (35 days).

Parameters	T1	T2	T3	T4	T5	T6	SE
Total feed intake (g/bird)	3632	3676	3534	3444	3448	3553	± 207.7
Final body weight (g/bird)	2645	2531	2577	2492	2534	2547	± 53.0
Final weight gain (g/bird)	2598	2484	2531	2446	2488	2501	± 52.4
Feed conversion ratio (g/g)	1.8	1.8	1.8	1.6	1.5	1.6	± 0.07

($p < .05$)

The results showed that the six different treatments did not have any effect on carcass composition or weight of body components of the broiler chickens (Table 13.3).

Table 13. 3. Carcass composition and mean weight of body components.

Parameters	T1	T2	T3	T4	T5	T6	SE
	Carcass Composition (%)						
Dry matter	34	35	34	33	34	34	± 1.4
Moisture	66	65	66	67	66	66	± 1.4
Fat	32	32	32	32	32	32	± 1.2
Protein	69	66	67	66	66	65	± 3.0
	Body Components (g/bird)						
Left half	884	903	941	860	938	987	± 65.9
Flesh	466	465	489	468	492	491	± 29.4
Skin	72	81	74	74	81	89	± 7.51
Bone	331	354	366	305	356	407	± 33.0
Dressing Percentage	72	71	72	73	72	72	± 0.64

($p < .05$)

13.2.2.2 The behaviour of broiler chickens

A summary of the results for feeding, drinking behaviours is presented in Table 13.4. Statistical analysis showed no differences between the six treatments.

Table 13. 4. Mean of feeding and drinking behaviours during the first 14 days experiment.

Parameters	T1	T2	T3	T4	T5	T6	SE
Feeding(no/b/h)	6.9	7.9	7.6	8.1	6.8	7.3	± 3.7
Drinking(no/b/h)	3.8	4.1	4.5	3.8	3.9	5.2	± 3.0

($p < .05$);no: number; b: bird; h: hour

13.2.3 Discussion

Feed consumption was lower when fat was added; T3, T4, T5 and T6 had a lower feed intake in comparison with T1 and T2 but the difference was not significant. Any real difference in feed consumption might be due to the increased fat level in the diet. If so, the results of the present study are similar to those obtained by Freitas *et al.* (2005) and Vieira *et al.* (2006), who reported the same trend but who did obtain significant results.

13.3 Experiment 15. Broiler Performances and Carcass Composition as Affected by Increasing Fat Supplemental. II: 1% Higher than Recommended at Different Periods.

Because the results of experiments 6 and 14 (2% and 3% fat higher than recommended fat content in diet) showed no significant differences in all parameter measurements relative to all controls, the experiments suggested the possibility (although not significantly) that a smaller level of fat increase is beneficial. Consequently, this experiment was carried out to see if increasing the fat level to only 1 % fat above control would produce improved meat quality in market-aged birds.

13.3.1 Materials and Methods

Materials and methods were as described for experiment 13.

13.3.1.1 Treatment

In this experiment a total of 120 one day old broiler chicks were randomly assigned to six dietary treatments groups of 20 birds each. Starter crumb and pellet, grower and finisher diets had two different fat levels (one as standard commercial diet and the other 1 % fat higher than higher than 1994 NRC specifications). There were 2 replicates with 10 birds each. The treatment groups are described in Box 13.2.

Box 13. 2. Treatments: feeding procedure; experiment 15

	Treatments					
Week	T1	T2	T3	T4	T5	T6
1	S crumb diet. . 4.6% fat	S crumb diet. 5.6% fat	S crumb diet. 5.6% fat	S crumb diet. 5.6% fat	S crumb diet. 5.6% fat	S crumb diet. 5.6% fat
2	S pellet diet. 6.7% fat	S pellet diet. 6.7% fat	S pellet diet. 7.7% fat	S pellet diet. 7.7% fat	S pellet diet. 7.7% fat	S pellet diet. 7.7% fat
3	Grower diet. 7.7% fat	Grower diet. 7.7% fat	Grower diet. 7.7% fat	Grower diet. 8.7% fat	Grower diet. 8.7% fat	Grower diet. 8.7% fat
4	Grower diet. 7.7% fat	Grower diet. 7.7% fat	Grower diet. 7.7% fat	Grower diet. 7.7% fat	Grower diet. 8.7% fat	Grower diet. 8.7% fat
5	Finisher diet. 9.1% fat	Finisher diet. 9.1% fat	Finisher diet. 9.1% fat	Finisher diet. 9.1% fat	Finisher diet. 9.1% fat	Finisher diet. 10.1% fat

T1: control groups; S: starter

All diets were provided *ad libitum*. The physical properties of the diets were standard.

13.3.1.2 Statistical analysis

Statistical analysis was as described for the previous experiment.

13.3.2 Results

13.3.2.1 The performance of broiler chickens

Statistical analysis of the weekly feed intake, body weight, weight gain, and feed conversion ratio results showed no differences between the six treatments (Table 13.5).

Table 13. 5. Mean weekly feed intake, body weight, weight gain and feed conversion ratio.

	Week				
Treatment	1	2	3	4	5
		Feed intake (g/bird/week)			
T1	152	443	767	1055	1596
T2	148	451	765	1099	1582
T3	148	440	751	1070	1575
T4	150	437	751	1069	1416
T5	148	445	732	1067	1484
T6	147	435	746	1050	1560
SE	± 7.6	± 28.7	± 35.0	± 53.6	± 103.5
		Body weight (g/bird/week)			
T1	193	532	1077	1770	2795
T2	189	528	1080	1806	2771
T3	188	509	1055	1776	2749
T4	193	535	1069	1779	2683
T5	193	534	1065	1793	2776
T6	189	529	1076	1796	2770
SE	± 9.5	± 28.7	± 56.2	± 65.8	± 11.3
		Weight gain (g/bird/week)			
T1	152	339	545	693	1025
T2	147	339	553	726	965
T3	146	322	546	721	973
T4	149	342	535	710	904
T5	149	341	531	729	983
T6	147	340	547	720	974
SE	± 7.2	± 20.8	± 29.4	± 34.4	± 58.8
		Feed conversion ratio (g /g)			
T1	1.00	1.3	1.4	1.5	1.6
T2	1.00	1.3	1.4	1.5	1.6
T3	1.01	1.4	1.4	1.5	1.6
T4	1.00	1.3	1.4	1.5	1.6
T5	099	1.3	1.4	1.5	1.5
T6	1.00	1.3	1.4	1.5	1.6
SE	± 0.02	± 0.03	± 0.03	± 0.08	± 0.05

($p < .05$)

There were no significant differences between the six treatments in terms of total feed intake, final body weight, weight gain, and feed conversion ratio. See Table 13.6.

Table 13. 6. Total feed intake, final body weight, body weight gain and feed conversion ratio of male broilers during whole period (35 days).

Parameters	T1	T2	T3	T4	T5	T6	SE
Total feed intake (g/bird)	4012	4043	3984	3822	3719	3937	± 169.4
Final body weight (g/bird)	2794	2771	2749	2683	2776	2770	± 111.3
Final weight gain (g/bird)	2753	2729	2707	2640	2733	2728	± 110.4
Feed conversion ratio (g/g)	1.6	1.6	1.6	1.6	1.5	1.6	± 0.06

($p < .05$)

The results showed that the six different treatments did not have any effect on carcass composition or weight of body components of the broiler chickens (Table 13.7).

Table 13. 7. Carcass composition and mean weight of body components.

Parameters	T1	T2	T3	T4	T5	T6	SE
	Carcass Composition (%)						
Dry matter	33	33	35	33	32	34	± 1.9
Moisture	67	67	65	67	68	66	± 1.9
Fat	33	34	34	35	35	36	± 1.2
Protein	65	63	66	63	63	64	± 2.6
	Body Components (g/bird)						
Left half	913	954	972	881	938	946	± 60.2
Flesh	511	540	531	518	474	491	± 31.3
Skin	82	91	92	88	86	93	± 6.7
Bone	293	307	330	334	349	333	± 53.2
Dressing Percentage	72	73	73	73	73	73	± 0.88

($p < .05$)

13.3.2.2 The behaviour of broiler chickens

A summary of the results for feeding, drinking behaviours is presented in Table 13.8. Statistical analysis showed no differences between the six treatments.

Table 13. 8. Mean of feeding and drinking behaviours during the first 14 days experiment.

Parameters	T1	T2	T3	T4	T5	T6	SE
Feeding (no/b/h)	7.9	8.6	8.5	8.7	8.6	9.8	± 3.5
Drinking (no/b/h)	4.5	5.0	4.9	5.3	5.6	6.4	± 2.9

($p < .05$); no: number; b: bird; h: hour

13.3.3 Discussion

We were unable to detect any significant differences in total feed intake, final body weight, weight gain, feed conversion ratio, and carcass quality between the six treatments. There are three possible reasons for this.

First, the different treatments genuinely had no effects on the variables tested. This is more than plausible. Second, the experiment lacked the power to detect any effects. Lack of power in experiments may be corrected by either of two methods—using a more powerful method of statistical analysis or increasing sample size (Field, 2000). In the case of the present experiment, between measures on-way ANOVA is more powerful than its alternative (Kruskal–Wallis). Without radical redesign of the experiment, there was no more powerful test available. Increasing the sample size plausibly might have detected a significant effect; however, in such an event it is highly likely that the effect size would have been trivial—that is, of no consequence to commercial poultry producers. Third, it is possible that the different treatments did produce different effects, but not in the time span investigated by the experiment. Whether this possibility is worth investigating is a matter of debate—clearly one could use this line of argument to continue investigating an alleged phenomenon ad infinitum.

Thus, for practical purposes, until such time as new evidence emerges to the contrary, it is safe to assume the different treatments had no effect.

13.3.4 General Discussion

The effects of added dietary fat level on broiler performance were evaluated in two trials. In Experiment 14, diets included 4.6% as standard commercial diet or 7.6% added soya oil. In Experiment 15, diets contained 4.6 % as in standard commercial diet or 5.6% added soya oil. Feeding of experimental diets was initiated from one-day-old broiler chicks to five-weeks-olds in trials. Neither broiler performance nor carcass composition was affected by dietary treatment.

Feed intake decreased as fat level of diet increased. The results were similar to those obtained by Freitas *et al.* (2005) and Vieira *et al.* (2006). Results presented in Tables 13.1–13.8 do not indicate that there were residual effects of treatments, for the parameters tested, in the different periods in the study. There were no significant effects between the fat level in diet in different periods and the final body weight at five weeks of broiler age. This finding accords with those of Peebles *et al.* (1997a, 1997b) and Noy and Sklan (2002).

These data suggest that certain dietary fat regimens may have, at most, only slight effects in small or young birds with regards to body weight, feed intake, and diverse physiological parameters. It is concluded that fat added at the 1% and 3% higher than recommended in current broiler diets has no noted negative effect on broiler performance and carcass quality. In the absence of any evidence to the contrary, this conclusion may be taken as it stands. The final chapter considers the results all experiments in the present study in relation to improving commercial poultry production.

Chapter 14: General Discussion

The experiments reported in this thesis have dealt with the effect of preference on feed intake, body weight, weight gain, and feed conversion of male broiler chicks under different conditions. It should be noted that the small number of the birds used in some experiments may have resulted in low statistical power to detect the marginal changes that occurred in the biometric parameters measured in this study. The major conclusions from the experiments conducted are discussed below.

Given the large number of statistical tests in the present study, it is likely that some of the significant results reported in it are Type I errors. Such errors are unavoidable in studies of this sort—the alternative is to set the criterion for statistical significance so demanding (by using, e.g., the Bonferroni adjustment) as to inflate the Type II error rate. In other words, being rigorous about statistical significance reduces power. In any event, the major findings of the present study, as discussed below, appear robust. They do not appear to have arisen from Type I errors.

The results of these experiments clearly showed that high fat diets (8%) improved feed intake at the first week of chick development. Experiment 1 and 4 show clearly that male broiler chicks preferred high fat feeding regimes in comparison to the other diets offered. Other studies have shown that birds are able to choose between combinations of at least two feeds, with final selections very accurately matching their physiological needs (Rose and Kyriazakis, 1991; Forbes and Shariatmadari, 1994; Covasa and Forbes, 1995; Forbes and Covasa, 1995).

It is well known that diet selection in birds is affected by preference and experience; social transmission of feeding behaviour is also possible (Chapple and Lynch, 1986, Malheiros *et al.*, 2003). Indeed, Shariatmadari and Forbes (1990) reported that when giving overnight-fasted broilers a meal of either high (HP) or low (LP) protein food, to which the birds had previously been accustomed, and then offering both a choice, significantly greater amounts of the opposite foods were eaten. When the initial meal was directly introduced into the crop by tube there was no subsequently significant preference observed, thus it appears that it is necessary for the bird to sample the food in order to predict its protein content based on previous experience of the two foods. Shariatmadari and Forbes (1992a, 1992b) have suggested that this strong tendency to switch between food types during feeding bouts leads to the proposition that food selection is to a large extent controlled by learned associations from prior consumption of foods and their hedonic properties. This is because a mechanism based upon continuous feedback from metabolic receptors would not be adequately influenced by the food eaten over very short time periods of feeding.

In experiment 2 and 3 it was found that a gradual change in feed offered no advantage in terms of broiler performance. From a commercial perspective, gradual change feeding is a more complicated and costly procedure to implement.

Experiment 5 showed that feeding a diet containing 2% more fat than NRC recommendations from 1 to 30 days of age in broiler chicks had a negative effect on body weight. Because high fat diets cost much more than low fat diets, there are no economic grounds for using fat supplement regimes at this level, especially since feed represents about 65% of total cost of production.

Experiment 6 showed that chicks can differentiate between colours of diet in such a way as to suggest that they have learned to associate feed intake with initial coloured diet consumed. In this trial, since there was no nutritional difference between the different coloured diets offered and no significant differences were seen in total feed intake of both colours, it can be concluded that the young chicks showed no inherent preference for either green or red coloured food. This result conforms to the impression given from previous studies of uncertainty concerning chicks' colour preferences.

Although many previous studies suggest that chickens show a preference for red and pink coloured diets (Hess and Gogel, 1954), some studies suggest preferences for blue colours (Hurnik *et al.*, 1970). Also, Roper and Marples, (1997) concluded that chicks have a hierarchy of colour preferences (black > green > red)—they found that chicks responded more readily to black crumbs than to red—and that these preferences are similar for food and water. In addition to such ambiguity concerning innate differences in colour preference, there is the possibility of imprinting over-riding any "innate" colour preferences. Similarly, chicks might innately prefer one colour in one context (e.g., feeding grain) and another colour in another context (e.g., when feeding mash). (Also, chicks might in general prefer ultra-violet—research on chick food colour preferences thus far has concentrated on what is visible to humans, not chickens.). The present study suggests that commercial poultry producers need not worry overmuch about chicks' colour preferences, though it is admitted that the issue demands further research.

It is unclear why the finding of the present study is different from that of others (however, one may note that different researchers have reported different instinctive colour preferences). More important , the finding of the present study accords with that of other studies, and with theory, in that chickens may acquire colour preference for food items—presumably by imprinting or classical conditioning—irrespective of any instinctive preferences that might (or might not) have. Indeed, chickens' plasticity of colour preference is supported by a variety of evidence.

Kennedy (1980), for example, showed that chickens have a long-term memory for colour, and in doing so manipulated their colour preferences. Kennedy reared two groups of newly hatched chicks on pelleted foods of a single colour—black, dark red, light red, yellow, blue or green. When the chicks were later offered a choice between the same coloured food and natural (uncoloured) food, birds of 28 weeks of age all preferred the coloured food previously consumed. Tested at 56 days the birds again showed a significant ($p < .05$) preference for the coloured food to which they have been previously exposed.

Experiments 7 and 8 showed that feed intake was improved by addition of 1.8 parts of water to 1 part dry food. It appears that the viscosity of food affects its nutritional value. This viscosity can be reduced by water treatment of the food (Gohl *et al.*, 1978). Yasar and Forbes (1996a, 1996b) found that addition of water to food (1.3 part:1 part) reduced the digesta viscosity; this may be part of the mechanism by which wet feeding increases feed intake. It also appears that the time between mixing food with water and offering it to the birds affects feed intake of wet feeds. This was suggested by the work of Yalda (1992), who concluded that soaking food improved feed intake when compared with air-dry food; the best results were when food was immediately soaked and presented to chicks—increasing the time between soaking and offering the food decreased feed intake.

As the percentage of water to dry food increases, food intake increases (but not significantly) (Yalda and Forbes, 1995a). Also providing drinking water with wet food affected daily feed intake; birds without drinking water consumed more wet food than birds with drinking water (Yalda, 1992), but both groups ate more than the birds fed dry food with drinking water. Intake of dry food of ducks was also seen to be significantly influenced by wetting the food. Yalda and Forbes (1995b) suggested this result was due to increased action of endogenous enzymes and reduced digesta viscosity and osmotic pressure of food.

Body weight gain of broilers increased when water was added at 1.2g/g dry food (Scott and Silversides, 2003). The wet-fed birds, (which were fed a wet starter crumb from 1–10 days after hatching, followed by dry food up to 21 days) gained significantly more efficiently during the first 10 days; and they had significantly heavier carcass weights at 21 days (Forbes, 2003).

Experiment 9 showed that the physical form of diet had a significant effect on feed consumption. Male broiler chicks ate more crumbs diet than pellet diet. The importance of physical form was found in previous studies. Savory (1974) conducted an experiment in which newly-hatched hybrid and brown Leghorn chicks were fed on diets in either pellet or mash form. The mash was made by grinding pellets. During the experiments, no chicks died over the first fifty days in any treatment, although thereafter mortality was seen among hybrids and Leghorns fed on mash and in hybrids fed on pellets: birds also showed symptoms of fowl paralysis. Over the first forty days, the birds offered a choice of food types consistently preferred mash to pellets. This strongly suggests that birds prefer mash to pellets, and that mash is healthier to birds than are pellets.

Munt *et al.* (1995) examined the effect of presentation method (pellets or mash, or as separate ingredients presented on a free-choice basis) on growth, carcase composition or profitability in chickens. They found that birds given a free choice varied widely in the proportions of ingredients eaten during the first 56h of the trial. Subsequently, the proportions consumed did not vary widely with birds given free-choice eating: about half of their intake was whole wheat, about one-third was concentrate (high-protein meals plus vitamin and mineral premixes), and about one-seventh was whole sorghum. By the end of the three-week trial, the average live body weights of the birds differed significantly according to method of feeding, with average weights in ascending order being observed for birds fed on pellets, mash, and free-choice. Again, this suggests mash is better than pellets; it also suggests free-choice feeding is healthier than forced-choice feeding.

When offered a choice of pellets or mash feed, birds preferred the feed they had previously been offered. However, behaviours were generally not affected by feed form experience (Skinner-Noble *et al.*, 2002).

One may note that the results of experiment 9 accord with such research. Crumbs are more similar to mash than they are to pellets, and the chicks in experiment 9 preferred crumbs.

Experiment 10 showed that when broiler chicks were offered a choice between unflavoured and flavoured diets, there was significant preference for unflavoured diet compared with garlic flavoured diet. The broiler chicks perceived something different in the flavoured diets and ate less of these. The likes and dislikes of broiler chicks in treatment 1, which showed an aversion to garlic flavoured feed, accord with the reviews by El Boushy and Kennedy (1987) and Balog and Millar (1989). However, the results are puzzling. Yalcin *et al.* (2006) found that added garlic powder to the diet of laying hens increased egg weight and decreased egg yolk cholesterol concentration and serum triglyceride and cholesterol concentrations without adverse effects on performance and egg traits. As regards adult birds, there seems no obvious reason for them to dislike garlic.

Garlic is very rich in aromatic oils, which enhance digestion and have a strong positive influence on the olfactory systems of many animals. The strong antioxidative effect of garlic would seem to be especially important when poultry feeds are supplemented with relatively high fat ingredients. The strong aromatic oils may easily penetrate ingredients used in feeds and improve their flavour, thus leading to improved consumption and digestion. The low preference of young chicks in this study for garlic-flavoured feed may have been an aversion to the newly introduced flavour. Alternatively, the aversion may have arisen because the proportion of garlic in the feed was very high.

Animals exposed to a variety of novel flavours show greater subsequent acceptance of these flavours than those with less prior exposure to novelty. For the immature but not the mature animals, there was a greater acceptance of novel foods in those that had previously been exposed to novel flavours (Kuo, 1967). Hennessy *et al.* (1977) gave newly weaned animals exposure to a variety of novel odours and found that those animals had subsequently greater acceptance of novel foods than had controls. Moreover, a single exposure of rats and chickens to a particular flavour or colour of a food can enhance consumption of that food (Siegel, 1974; Braveman and Jarvis, 1978). In these species, the enhanced intake is generally short lived.

As indicated (Chapter 2), some authors suggest that animals possess nutritional wisdom. Other authors reject the idea. Morgan (1984), for example, concluded that animals make no instinctive discrimination. He believed that selection or rejection of food was dependent solely on individual experience. One can leave this question open. As regards the present study, one need only make two points. First, domesticated animals do not necessarily have the same skills as their feral ancestors—Jones (1999) reports that domestic dogs are less "intelligent" than the wolves from which they evolved; and he says the same about chickens and wild fowl (wild fowl appear more intelligent than chickens). Given this, even if feral birds were nutritionally wise, there is no reason to suppose domesticated poultry to have retained the wisdom—chickens, after all, have not retained the ability to fly. Second, the object of the present study was to ascertain what is good for poultry producers, not poultry. Although, within reason, poultry producers want to produce healthy birds, an optimally healthy bird might not necessarily be the most commercial one—an optimally healthy bird might, for example, have very tough meat.

Experiments 11 through 15 investigated the effects of increased fat in the feed of chicks. In general, the results indicated little effect. However, young chicks preferred a high fat diet.

Experiment 11 showed that the chicks consumed the supplemental fat when given separately; this could be attributed to the taste, palpability, texture, smell, and so on, of the supplement or to the chicks' physiological need for the high energy food source. The high utilization rates by young birds of feed fats may be indicative of their similarly high fat dependence from yolk sac sources during the first few days after hatching (Freeman, 1965; Broom, 1968, Rogers, 1989; Forbes 1995; Appleby *et al.*, 2004). Similarly, experiment 12 showed that the chicks consumed significantly more from (4.6%fat + 24% protein diet) and (8.0%fat + 26% protein diet) compared to (4.6%fat + 26% protein diet) during the second week.

Experiment 13 showed that feeding diet with high fat level (8%) for 1st wk followed by feeding diet with high fat level (8%) and high protein percent (26%) or feeding diet with high protein percent (26%) for 2nd wk had no irreversible effect on performances of chickens at market age. Experiments 14 and 15 likewise showed no significant effects between the fat level in diet in different periods and the final body weight at five weeks of broiler age. These results are perplexing. If, as some suggest, animals have "nutritional wisdom", the young chicks' predilection for high fat food was good for them. Yet the experiments failed to find any beneficial effects (but is failed to find any adverse ones, too).

If, on the other hand, animals do not have "nutritional wisdom", it is hard to explain why the chicks' predilection for high fat food ceased after a week. All one can say at this stage is that high fat diet failed to do the chicks any harm, and that it might have done them some good (or bad), but that the present study lacked the power to detect any such effects, if present. This suggests that any long-term effects of early high fat diets, good or bad, if they exist, are relatively trivial.

In summary, there is strong evidence that high fat diet is preferred by male broiler chicks; also, it seems that male broiler chicks are born with certain inbuilt preferences that can be adapted or changed completely as a result of learning. This learning can be accelerated by using parallel cues and stimuli, and if the cue and stimuli are reversed, suitable adjustments can be made by birds.

Regardless of the advantages and the disadvantages of free selection in the first week of broiler lives found from the experiments in the present study, overall the complete study leaves some important questions unanswered. Although much experimental work has been done, more research is needed on the effects of free-choice selection and high fat starter crumbs diets in the first days of broiler chicks' lives. Such research needs to incorporate studies of 1) free range systems, 2) sex and poultry genotypes, 3) different environmental temperature, and 4), metabolic and other physiological mechanisms.

The results of the present study relate to the combination of free selection and high fat starter crumbs diets when applied in first days of broiler chick's development. One hopes this will help poultry production and welfare: the present study suggests poultry producers need not be paranoid about feeding young chicks fat. However, full understanding of chicks' dietary preferences and the rules that govern them is at present lacking; such understanding is necessary if we are to determine the precise economic consequences of different feeds and feeding conditions.

Overall, gain in weight in the first week of a broiler's life has the most important impact on the market weight of chickens; thus one hopes that results from the present study, particularly those that show that enhanced body weight gain can be achieved by giving the male broiler chicks a high fat starter diet, may allow for more rapid gains or for a greater quantity of meat to be produced in a given time—costs of housing, equipment, and labour may be reduced. On the other hand, the ingredient and production costs of higher energy diets, in contrast to diets of lower energy density, may negate the benefits of improved performance. The latter issue, however, is a subject for further research.

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Appendices

Appendix 1: Diet

Composition of diet 1

		Fresh	10% H2O			Fresh	10% H2O
Total	%	100.00	100.95	Isoleucine	%	1.09	1.10
Moisture	%	11.24	10.00	Leucine	%	1.95	1.97
Crude Oil	%	4.61	4.65	Phenylalanine	%	1.15	1.16
Crude Protein	%	24.09	24.32	Valine	%	1.17	1.18
Crude Fibre	%	3.01	3.04	Tyrosine	%	0.88	0.89
Ash	%	6.59	6.65	Taurine	%	0.00	0.00
NFE	%	50.26	50.74	Glycine	%	2.29	2.31
Total Dietary Fibre	%	9.66	9.75	Aspartic Acid	%	1.59	1.61
Pectin	%	1.06	1.07	Glutamic Acid	%	3.92	3.96
Hemicellulose	%	5.28	5.33	Proline	%	1.28	1.29
Cellulose	%	2.64	2.67	Serine	%	1.08	1.09
Lignin	%	0.67	0.68	Alanine	%	0.08	0.08
Starch	%	40.01	40.39	Hyd.Proline	%	0.09	0.09
Sugar	%	3.58	3.61	Hyd. Lysine	%	0.00	
Gross Energy	MJ/kg	15.38	15.53	Ca	%	1.04	1.05
C14 1 Myristoleic	%	0.02	0.02	P Total	%	0.82	0.83
C16 1palmitoleic	%	0.20	0.20	P Phytate	%	0.16	0.16
C18 1 W9 Oleic	%	1.03	1.04	P Available	%	0.66	0.67
C18 2 W6 Linoleic	%	1.53	1.54	Na	%	0.19	0.19
C18 3 W3 Linolenic	%	0.16	0.16	Cl	%	0.27	0.27
C20 4 W6 Arichidonic	%	0.21	0.21	K	%	0.95	0.96
C22 5 W3 Clupanodonic	%	0.06	0.06	Mg	%	0.16	0.16
C12:0 Lauric	%	0.04	0.04	Fe	mg/kg	105.5	106.5
C14:0 Myristic	%	0.14	0.14	Cu	mg/kg	12.5	12.7
C16:0 Palmitic	%	0.32	0.32	Mn	mg/kg	104.6	105.6
C18:0 Stearic	%	0.09	0.09	Zn	mg/kg	83.6	84.4
Arginine	%	1.69	1.71	Co	µg/kg	337.4	340.6
Lysine	%	1.42	1.43	I	µg/kg	1552.2	1566.9
Methionine	%	0.65	0.66	Se	µg/kg	372.6	376.2
Cystine	%	0.35	0.35	F	mg/kg	9.8	9.9
Tryptophan	%	0.27	0.27	Vitamin A	iu/kg	11985	120998
Histidine	%	0.62	0.63	Vitamin D3	iu/kg	4500.0	4542.9
Threonine	%	0.95	0.96	Vitamin E	iu/kg	27.5	27.7

Ingredients Diet 1

Ingredient	% Inclusion
Wheat	39.34
Maize	23.00
Soya 48%	22.75
Fish Meal	10.00
Soya Oil	1.20
Limestone	1.00
Pot Dihydrogen Phosp	1.00
Sunflower Oil	0.75
Premix	0.50
Dl-Methionine	0.26
L-LYSINE Hcl	0.10
Salt	0.05
Sodium Bicarbonate	0.05

Composition of diet 2

		Fresh	10% H2O			Fresh	10% H2O
Total	%	100.00	100.95	Isoleucine	%	1.08	1.09
Moisture	%	11.08	10.00	Leucine	%	1.92	1.94
Crude Oil	%	6.03	6.09	Phenylalanine	%	1.13	1.14
Crude Protein	%	23.73	23.96	Valine	%	1.16	1.17
Crude Fibre	%	2.96	2.99	Tyrosine	%	0.87	0.88
Ash	%	6.49	6.55	Taurine	%	0.00	0.00
Nfe	%	49.51	49.98	Glycine	%	2.25	2.27
Total Dietary Fibre	%	9.51	9.60	Aspartic Acid	%	1.57	1.58
Pectin	%	1.04	1.05	Glutamic Acid	%	3.86	3.90
Hemicellulose	%	5.20	5.25	Proline	%	1.26	1.27
Cellulose	%	2.60	2.62	Serine	%	1.07	1.08
Lignin	%	0.66	0.67	Alanine	%	0.08	0.08
Starch	%	39.41	39.79	Hyd.Proline	%	0.09	0.09
Sugar	%	3.52	3.55	Hyd. Lysine	%	0.00	
Gross Energy	Mj/Kg	15.73	15.88	Ca	%	1.03	1.04
C14 1 Myristoleic	%	0.02	0.02	P Total	%	0.81	0.82
C16 1palmitoleic	%	0.22	0.22	P Phytate	%	0.16	0.16
C18 1 W9 Oleic	%	1.30	1.31	P Available	%	0.65	0.66
C18 2 W6 Linoleic	%	2.08	2.10	Na	%	0.19	0.19
C18 3 W3 Linolenic	%	0.25	0.25	Cl	%	0.26	0.26
C20 4 W6 Arichidonic	%	0.21	0.21	K	%	0.94	0.95
C22 5 W3 Lupanodonic	%	0.06	0.06	Mg	%	0.16	0.16
C12:0 Lauric	%	0.06	0.06	Fe	Mg/Kg	103.9	104.9
C14:0 Myristic	%	0.19	0.19	Cu	Mg/Kg	12.34	12.5
C16:0 Palmitic	%	0.40	0.40	Mn	Mg/Kg	103.0	103.9
C18:0 Stearic	%	0.14	0.14	Zn	Mg/Kg	82.3	83.1
Arginine	%	1.66	1.68	Co	Mg/Kg	332.3	335.5
Lysine	%	1.40	1.41	I	Mg/Kg	1529	1543.5
Methionine	%	0.64	0.65	Se	Mg/Kg	367.0	370.5
Cystine	%	0.35	0.35	F	Mg/Kg	9.7	9.8
Tryptophan	%	0.26	0.26	Vitamin A	Iu/Kg	11805	11917
Histidine	%	0.61	0.62	Vitamin D3	Iu/Kg	4433	4475
Threonine	%	0.94	0.95	Vitamin E	Iu/Kg	28.7	28.9

Ingredients diet 2

Ingredient	% Inclusion
Broiler starter as diet 1	98.50
Soya oil-crude degummed	1.50

Composition of diet 3

		FRESH	10% H2O			FRESH	10% H2O
Total	%	100.00	100.95	Isoleucine	%	1.05	1.06
Moisture	%	10.85	10.00	Leucine	%	1.88	1.90
Crude Oil	%	8.02	8.10	Phenylalanine	%	1.11	1.12
Crude Protein	%	23.22	23.44	Valine	%	1.13	1.14
Crude Fibre	%	2.90	2.93	Tyrosine	%	0.85	0.86
Ash	%	6.35	6.41	Taurine	%	0.00	0.00
Nfe	%	48.46	48.92	Glycine	%	2.20	2.22
Total Dietary Fibre	%	9.31	9.40	Aspartic Acid	%	1.54	1.55
Pectin	%	1.02	1.03	Glutamic Acid	%	3.78	3.82
Hemicellulose	%	5.09	5.14	Proline	%	1.23	1.24
Cellulose	%	2.55	2.57	Serine	%	1.05	1.06
Lignin	%	0.65	0.66	Alanine	%	0.08	0.08
Starch	%	38.57	38.94	Hyd.Proline	%	0.08	0.08
Sugar	%	3.45	3.48	Hyd. Lysine	%	0.00	
Gross Energy	Mj/Kg	16.23	16.38	Ca	%	1.01	1.02
C14 1 Myristoleic	%	0.02	0.02	P Total	%	0.79	0.80
C16 1palmitoleic	%	0.25	0.25	P Phytate	%	0.16	0.16
C18 1 W9 Oleic	%	1.68	1.70	P Available	%	0.63	0.64
C18 2 W6 Linoleic	%	2.84	2.87	Na	%	0.18	0.18
C18 3 W3 Linolenic	%	0.38	0.38	Cl	%	0.26	0.26
C20 4 W6 Arichidonic	%	0.21	0.21	K	%	0.92	0.93
C22 5 W3 Clupanodonic	%	0.05	0.05	Mg	%	0.15	0.15
C12:0 Lauric	%	0.09	0.09	Fe	Mg/Kg	101.7	102.7
C14:0 Myristic	%	0.25	0.25	Cu	Mg/Kg	12.1	12.2
C16:0 Palmitic	%	0.51	0.51	Mn	Mg/Kg	100.8	101.8
C18:0 Stearic	%	0.21	0.21	Zn	Mg/Kg	80.6	81.4
Arginine	%	1.63	1.65	Co	Mg/Kg	325.2	328.3
Lysine	%	1.37	1.38	I	Mg/Kg	1496.3	1510.6
Methionine	%	0.62	0.63	Se	Mg/Kg	359.2	362.6
Cystine	%	0.34	0.34	F	Mg/Kg	9.5	9.6
Tryptophan	%	0.26	0.26	Vitamin A	Iu/Kg	11553	11663
Histidine	%	0.60	0.61	Vitamin D3	Iu/Kg	4338.0	4379.4
Threonine	%	0.92	0.93	Vitamin E	Iu/Kg	30.4	30.7

Ingredients diet 3

Ingredient	%Inclusion
Broiler starter as diet 1	96.40
Soya oil-crude degummed	3.60

Feed specification

	Starter (Crumb)	Grower (pellet)	Finisher (Pellet)
Age Fed	0 to 10	11 to 28	+28
Raw Material			
Wheat	62	64.7	71.348
Fishmeal	5.5	3	1.5
Hipro Soya	26.3	23.1	17.5
Premix	0.25	0.25	0.25
Lysine	.168	0.172	0.187
Methionine	0.295	0.263	0.216
Threonine	0.073	0.071	0.078
Choline chloride	0.083	0.083	0.083
Enzyme	0.1	0.1	0.1
Salmonellae Inhib	0.6	0.6	0.6
Limestone	1.126	1.151	1.152
MCP	1.028	1.129	1.29
Salt	0.031	0.032	0.065
Sodium Bicarb	0.158	0.264	0.281
Soya Oil	1.3	1.9	0.85
Fat Mix	1	3.2	4.5

Crumb of 0.7-0.9mm diameter from 0 and 10 days of age; Pellet of 2mm diameter from 11 and 28 days of age; Pellet of 3mm diameter from 29days to kill.

Appendix 2: Behaviours

Description of recorded behaviours

Feeding	with head above or in the feeder
Drinking	drinking from the drinker
Sleeping	with the head flat on the bedding or the head under a wing either with eyes open or closed
Standing	standing without any other activity
Sitting	sitting with hocks resting on ground with out other activity
Walking	locomotion with a normal speed or with quick steps
Wing/Body Stretching	stretching of wing and/or leg and body
Aggression	pecks directed to the head or feather of pen mate
Floor pecking	pecking object at ground
Body Grooming	grooming of own feathers with beak

Appendix 3: Equipment for chemical analysis

Fat Analysis

Soxtec 2050 auto analyzer unit*

Nitrogen Analysis

Kjeltec 2300 auto analyzer unit*

*: FOSS; 730 Birchwood Boulevard; Birchwood; Warrington WA3 7QY; Cheshire, UK.

Appendix 4: ANOVA tables

Experiment 1. ANOVA table

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Diet	2	88748	88748	44374	4.42	0.019
Day	1	605800	605800	605800	60.36	0.000
Error	35	351291	351291	10037		
Total	38	1045840				

Experiment 2. ANOVA table

Source	DF	SS	MS	F	P
Fat Level	1	14671	14671	0.04	0.851
Group	2	16309	8154	0.02	0.981
Fat Level*Group	2	25123	12562	0.03	0.970
Error	198	81992638	414104		
Total	203	82048741			

Experiment 3. ANOVA table

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Fat Level	2	2012	2012	1006	18.22	0.000
Group	1	5	5	5	0.10	0.758
Fat Level*Group	2	1301	1301	651	11.78	0.000
Day	34	964580	964580	2837	513.69	0.000
Error	170	9389	9389	55		
Total	209	977288				

Experiment 4. ANOVA table

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Treatment	1	361	361	361	0.49	0.494
Replicate	2	8418	8418	4209	5.68	0.011
T*R	2	4725	4725	2363	3.19	0.063
Week	4	5217468	5217468	1304367	1760.18	0.000
Error	20	14821	14821	741		
Total	29	5245793				

Experiment 5. ANOVA table

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Week	4	596144	5961444	1490361	1692.57	0.000
Treatment	1	35429	35429	35429	40.24	0.000
Replicate	5	44907	44907	8981	10.20	0.000
W*T	4	19519	19519	4880	5.54	0.001
Error	45	39624	39624	881		
Total	59	61009				

Experiment 6. ANOVA table

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Treatment	1	0.0133	0.0133	0.0133	0.18	0.686
Colour	1	0.0133	0.0133	0.0133	0.18	0.686
T*C	1	4.5633	4.5633	4.5633	60.18	0.000
Error	8	0.6067	0.6067	0.0758		
Total	11	5.1967				

Experiment 7. ANOVA table

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Treatment	2	0.1050	0.1050	0.0525	0.40	0.673
Diet form	1	0.0469	0.0469	0.0469	0.36	0.554
T*Df	2	0.3439	0.3439	0.1719	1.31	0.284
Error	30	3.9317	3.9317	0.1311		
Total	35	4.4275				

Experiment 8. ANOVA table

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Treatment	1	0.2250	0.2250	0.2250	4.02	0.052
Diet form	1	4.0960	4.0960	4.0960	73.22	0.000
T*Df	1	0.0810	0.0810	0.0810	1.45	0.237
Error	36	2.0140	2.0140	0.0559		
Total	39	6.4160				

Experiment 9. ANOVA table

Source	DF	SS	MS	F	P
Treatment	1	12	12	0.03	0.874
Diet form	1	219632	219632	466.50	0.000
T*Df	1	1742	1742	3.70	0.062
Error	36	16949	471		
Total	39	238336			

Experiment 10. ANOVA table

Source	DF	SS	MS	F	P
Treatment	1	12	12	0.03	0.874
Flavour	1	219632	219632	466.50	0.000
T*F	1	1742	1742	3 70	0.062
Error	36	16949	471		
Total	39	238336			

Experiment 11. ANOVA table

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Treatment	1	1.1	1.1	1.1	0.01	0.929
Fat supplement	1	2968.1	2968.1	2968.1	22.08	0.000
T*Fs	1	147.3	147.3	147.3	1.10	0.300
Error	56	7528.5	7528.5	134.4		
Total	59	10644.9				

Experiment 12. ANOVA table

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Diet	2	577.85	577.85	288.93	8.08	0.002
Day	6	1180.82	1180.82	196.80	5.50	0.001
D*D	12	252.51	252.51	21.04	0.59	0.827
Error	21	750.80	750.80	35.75		
Total	41	2761.98				

Experiment 13. ANOVA table

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Week	4	10585282	10585282	2646320	4293.14	0.000
Treatment	2	1703	1703	852	1.38	0.262
Replicate	3	9202	9202	3067	4.98	0.005
W*T	8	1840	1840	230	0.37	0.929
Error	42	25889	25889	616		
Total	59	10623917				

Experiment 14. ANOVA table

Source	DF	Seq SS	Adj SS	Adj MS	F	P
T	5	89133	89133	17827	0.55	0.739
R	1	95408	95408	95408	2.92	0.148
Error	5	163546	163546	32709		
Total	11	348087				

Experiment 15. ANOVA table

Source	DF	Seq SS	Adj SS	Adj MS	F	P
T	5	14231	14231	2846	0.01	1.000
R	1	2954	2954	2954	0.01	0.917
Error	53	14135797	14135797	266713		
Total	59	14152983				