EFFECTIVE CALORIC VALUE OF NUTRITIONAL AND NON-NUTRITIONAL COMPONENTS OF BROILER NUTRITION

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Format of Dissertation

This thesis presented in the Journal of Poultry Science style and format allowing for independent chapters to be suitable for submission to scientific journals. Two papers have been prepared from research data collected at Oklahoma State University to partially fulfill the requirements for the degree of Doctor of Philosophy. Each paper is complete in itself containing an abstract, introduction, materials and methods, results, discussion, implication, and literature cited section.

CHAPTER I

INTRODUCTION

The broiler industry is new relative to other livestock production systems. It started in the east cost region of the United States in the 1920s (USDA, 2005). The evolution and success of the broiler industry is in part attributed to its vertically integrated corporate structure, which to a certain extent provides continuity among broiler flocks. Broilers are reared globally under a wide range of conditions, differing facilities and equipment, as well as environmental and animal welfare regulations. In the U.S., broiler meat production for 2005 is projected to be close to 16 million metric tons, which is approximately 40% of the total animal protein market (Haley, 2005).

The high demand for broiler meat makes it imperative to have in depth knowledge and continually strive to improve both the genetics and rearing environment. Genetics refers to the gene pool production potential whereas environment is a broad term which refers to nutritional and non-nutritional factors.

Intensive genetic selection of commercial strains for growth rate in broilers has resulted in higher producing broilers. Indeed, today's growth rate is about 2.5 times as much as of birds of 60 years ago. Such genetic progress has been accompanied with certain unfavorable indirect selection responses in other traits (Siegel and Dunnington, 1987). One undesirable response in this regard is excessive fat deposition, which in recent years has been of increasing concern to consumers. Despite the great

improvements attained to date by genetic selection, there is still variability from flock to flock, and factors impacting bird energy expenditure appear to be significant.

Nutritional factors include bird nutrient requirements and diet, nutrient content, caloric density, protein content, calorie to protein ratio and balance where as nonnutritive factors include stocking density (Cravener et al., 1992; Puron et al., 1997), lighting program (Buyse et al., 1996; Ingram et al., 2000), ventilation (Lott et al., 1998; Yahav et al., 2004) and feed form (Acar et al., 1991; Moritz et al., 2001). Though the precise mode of action by which such nonnutritive factors impact broiler performance may be subject to debate, one could conclude each as having a nutritional consequence to the bird in terms of energy expenditure. Though nonnutritive factors influence energy expenditure they are not generally considered as variables directly influencing desired ration formulation.

Dietary energy comprises a major cost in poultry production. Energy needs for maintenance, protein and fat accretion are dynamic and change continuously during the growth of an animal (Milgen, 2002). Evaluations concerning the efficiency of animal growth have often been based on the partitioning of metabolizable energy intake between maintenance, growth and other production functions. Partitioning of energy intake between maintenance and production functions has been a convenient and useful means to study whole animal metabolism. Accurate and precise data describing the energy requirements of poultry are needed to formulate more efficient and less costly diets. Knowledge of broiler energetics as well as managerial (non-nutritional) practices that have direct bearing on broiler performance are evolving and new and improved approaches that target these fundamentals are being developed.

The metabolizable energy (MEn) system is the accepted standard for ration formulation (NRC, 1994). The Men system largely represents bird ability to digest feedstuff. Though the MEn system is correlated with bird energy deposition (Wiernusz, 1994), it is unable to account for non-nutritional factors such as effects of light, feed form, and stocking density that affect performance. These non-nutritional factors may affect energy/nutrient utilization, thereby affecting body composition through differences in composition of gain.

Low protein diets are lipogenic due to the greater heat increment from protein MEn calories compared with the calories from starch and fat. Energetic efficiency of broilers for use of protein or any other substrate is the net result of partitioning of the substrate energy consumed into maintenance or lean and lipid accretion. Mittelstaedt (1990) examined true metabolizable energy (TME) utilization of carbohydrate, protein and fat sources for energy, protein and fat gain. He reported despite similar TME consumption among the energy supplemented groups, carcass energy was impacted significantly and total carcass energy gain was 17, 27, and 30% greater for gelatin, starch, and corn oil groups than birds fed the basal diet.

Efficiency of ingredient TME use for carcass energy deposition averaged 50.0, 39.1, and 19.9% for supplemental corn oil, starch and gelatin respectively. Energetic efficiency of MEn use for tissue gain varies with substrate source, for lipogenesis being approximately 75, 84, and 61% for carbohydrates, fats and proteins, respectively (De Groote, 1969).

Diets formulated, based on the MEn system do not perfectly correlate with bird energy retention as heat production is not accounted for. As a result the net calorie-

nutrient ratios can vary independently of metabolizable energy. Any energy requirement system employed must account for substrate mediated heat production for the bird to achieve maximum tissue accretion with minimum fat deposition.

Dietary energy comprises a major cost in poultry production. Energy needs for maintenance, protein and fat accretion are dynamic and change continuously during growth of the animal. Evaluations concerning the efficiency of animal growth have often been based on the partitioning of metabolizable energy intake between maintenance, growth and other production functions. Partitioning of energy intake between maintenance and production functions has been a convenient and useful means to study whole animal metabolism. Accurate and precise data describing the energy requirements of poultry are needed to formulate more efficient and less costly diets.

Looking at the nutritional factor closely, there is an inherent caloric cost associated with accretion of lean and lipid tissues, the associated inefficiencies of which contribute to heat production. In an effort to quantify these costs, Kielanowski (1965) subdivided retained energy as: $ME = ME_m + (1/k_p \times ERP) + (1/k_f \times ERF)$, where: ME = metabolizable energy intake, ME_m = metabolizable energy required for maintenance, ERP = energy retained as protein, ERF = energy retained as fat, k_p = efficiency of energy utilization for protein, and k_f = efficiency of energy utilization for fat. And through regression analysis obtained values for ME_m, k_p, and k_f. This regression approach, however, has received criticism due to the autocorrelation among the variables (Emmans, 1994; Noblet et al., 1999; Milgen and Noblet, 1999), and its inability for separating metabolizable energy into dietary substrates from which it is derived (Noblet et al., 1993).

Any approach to estimating the efficiency of energy utilization for tissue accretions requires a good understanding of energy required for maintenance. Errors or assumptions made relative to the maintenance energy requirement are carried-over resulting in an over or under estimation of energy available for gain and ultimately incorrect estimates for the metabolic costs of tissue accretion. Little research as of late has been directed at understanding maintenance energy need in broilers or factors that may alter maintenance energy requirement.

Future improvements in poultry nutrition are likely to come from improved nutrient utilization and minimized energy waste as energy expenditure, rather than improving the feedstuff itself. It is therefore imperative that management (lighting, housing, watering, stocking density, and immune challenge) improvements should be revisited.

The objective of the studies reported in this thesis was to quantify metabolizable energy required for maintenance and tissue accretion and to evaluate the energetic efficiencies of protein, carbohydrate, and fat and the additivity of these substrates for tissue accretion and fat deposition. Furthermore, the study also investigated the effects of light as a managerial tool on metabolic factors associated with energetic efficiency. Data collected and its outcome will further enrich our knowledge of energy metabolism of the three substrates and the effects of light, a non-nutritional factor, for all phases of broilers.

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CHAPTER II

REVIEW OF LITERATURE

Introduction

Knowledge of metabolism of nutrients and energy derived from feed substrates is fundamental to diet formulation and profitable broilers industry. The metabolizable energy (ME) system is the accepted standard for ration formulation (NRC, 1994). This system, however, is not without its limitations. ME does not quantitatively predict energy deposition by the birds and does not account for heat increment resulting from basal metabolism, substrate utilization, activity, diseases and energetic costs of immune challenge, social stress created by other animals and man, malnutrition, toxicities, and the thermal environment. To meet the current market demand for maximum protein deposition with minimal fat accretion, an energy scheme that takes into account the variations in heat production resulting from utilization of various substrates is essential.

Knowledge of the utilization of the three important nutrients, namely, protein; fat and carbohydrate is of paramount important in broiler production. This study will be devoted to giving an insight into substrate utilization and managerial effects mainly, lighting program, to enhance ration utilizable net energy thereby optimizing lean tissue growth without excessive fat accretion through feeding diets to produce optimal cellular energy /nutrient ratios.

BIOENERGETICS

Bioenergetics also sometimes referred as biochemical thermodynamics is the quantitative analysis of how organisms gain and use energy. It is part of the general science of energy transformations, which is called thermodynamics (Mathews et al., 2000). Energy has different forms such as mechanical, thermal, electrical, light, nuclear, and molecular or chemical. Although the form of the energy may change, the total amount of energy of a system remains constant which is referred as the first law of thermodynamics. Molecular energy is the useful form of energy to animals. The animal nutritionist deals with the utilization of chemical energy stored in the feed to sustain animal life and for tissues accretion, and the metabolic processes associated with it.

A broiler chicken is a dynamic structure, which grows, moves, synthesizes complex macromolecules, and selectively shuttles substances in and out between compartments, using energy acquired from feed consumed. As energy plays a central role in the life of poultry in general and the broiler chicken in particular, a clear understanding of bioenergetics for all poultry classes is fundamental to diet formulation and achievements of biologically efficient broilers.

Cells of living organisms are open systems that continuously exchange matter and energy with their environment. Living organisms use either of two strategies to derive energy from their surroundings: (1) they take up chemical fuels from the environment and extract energy by oxidizing them; or (2) they absorb energy from sunlight. Open systems are in a dynamic steady state rather than in a state of true thermodynamic equilibrium. The continuous orderly procession of enzyme catalyzed chemical reactions involved in these exchange process constitute the subject of metabolism.

In the physical sciences, energy is designated as broadly to be work or anything that can be converted to work. This definition, however, is one of several uses of energy in biology, particularly in the living animal. In physical as well as in chemical systems, the capacity to perform useful work depends upon the expenditure of energy, and a certain quantity of this energy may be stored for future use. In a chemical system, potential chemical energy may be stored in the form of covalent bonds for release and utilization at some future time. In animal systems, the energy equivalent of work, the maintenance energy of the animal, and the heat increment of feeds equals the energy generated from the oxidation of nutrients of the feed (Brody, 1964).

BASAL METABOLISM AND METABOLIC BODY SIZE

The total of all the chemical reactions taking place in the body of an animal is called its metabolism, and the sum of the rates of the reactions is the metabolic rate of the body (Stanier, et al., 1984). Heat is produced as a by-product of metabolic processes that occur in the body and heat production increases after a meal, during physical activity, and in temperatures that are outside the animal's thermoneutral zone (McDonald, 1995). Age, time of day, thermal insulation, and various organs within the body also contribute to higher heat production by the animal (McDonald, 1995). In the latter case, Stainer et al., (1984) reported that, in humans at rest and in a thermoneutral environment, one-half of all the heat produced comes from the gastrointestinal tract, liver, and muscle metabolism.

Basal metabolic rate (BMR) measures heat production of an animal that is rested, awake, fasting (post absorptive), and in the thermoneutral zone (McDonald et al, . BMR is the minimum metabolic rate deriving the normal physiological processes of life, such

as energy required for cellular activity, respiration, circulation, nerve impulses, and maintaining body temperature. Basal metabolic rate can be determined by direct calorimetry, which is a measure of heat loss, and by indirect calorimetry (Bartels, 1973), which determines heat production (HP) based on gaseous exchange. Since most of the exothermic reactions in the body of broiler chickens depend on oxidation, indirect calorimetry**,** which a measurement of oxygen consumption can be employed to estimate metabolic rate.

Determination of BMR is made difficult by problems related in establishing conditions necessary to determine BMR. These include attaining thermoneutral temperature for different strains of birds, or for different age groups of birds, and the post absorptive state that may vary depending on the level of previous meal (Bender, 1993). Therefore, standardizing the conditions under which BMR is determined is necessary. Metabolic rate measured under such conditions is called standard metabolic rate. Further practical problems may arise if the measurements are made on animals other than human subjects, due to the difficulty of controlling animal emotion and related activities. One possibility however, is to do measurements when the animal is showing all the physical signs of rest, which is called resting metabolic rate (Bender, 1993). In some studies, resting metabolic rate measurement was accomplished by keeping birds in the dark during the measurement of heat production (Bender, 1993). Mission (1974), found that several training sessions were necessary to accustom the domestic fowl to the experimental situation before basal values were measured. Between 24 and 48 h without food, depending on the size of the bird, were also noted to be necessary to reach a post absorptive state (Mission, 1974).

BMR is a function of the animal's surface area (Brody, 1964). Surface area and basal metabolism per unit body weight decline with increasing body weight. Since surface area is a difficult trait to measure, attempts have been made to relate it to body weight (Brody, 1964). Body weight raised to a power 0.75 is typically considered to be the metabolic weight of the animal (Brody, 1964). For mature birds however, the exponent varies from 0.62 to 0.70 (Brody, 1964). Metabolic weight of $BW^{.66}$ for poultry is commonly reported to provide a better estimate. There is a variation in the metabolic rate of birds during the course of the day that is independent of the effects of feed intake (circadian rhythm), although feed consumption contributes to the rhythm in the birds that are fed. Activity contributes to the circadian rhythm but the circadian rhythm in fasting fowls is not entirely the result of changes in activity. The cycle of light and darkness also plays a part.

FEED SUBSTRATE ENRGY METABOLISM

Determining the level of energy of a diet is important in formulating diets for poultry. Energy alone contributes to about 70% of the total cost of poultry diets (Skinner et al., 1992); thus, choosing the proper level of energy that will optimize growth, carcass quality and feed efficiency, while still allowing for profitable production is a major concern to any integrator. For a number of years, it has generally been assumed that chickens tend to eat to meet their energy needs, provided that the diet is adequate in essential nutrients (Hill and Dansky, 1954). However, it has shown that if essential dietary nutrients are maintained in relationship to dietary energy, increased growth rate and improved feed efficiency is observed with increasing levels of dietary energy (Farrell et al., 1976; Waldroup, 1981; Jackson et al., 1982; Sohn and Han, 1983a, 1983b; Bartov,

1992; Leeson et al., 1996). Hence, higher energy levels may allow for more rapid gains or for a greater quantity of meat to be produced in a given time so that capital costs of housing, equipment and labor may be reduced.

Higher dietary energy level may be more economical if it provides a more rapid rate of gain and greater number of flocks per year (McDonald and Evans, 1977). On the other hand, the ingredient and production costs of higher energy diets in contrast to diets of lower energy density may offset the benefits of improved performance (Waldroup, 1981; Brown and McCartney, 1982). Hence, using diets higher in nutrient density has to be dictated by feed cost and output. Carcass fatness may not change as long as the C:P (calorie to protein ratio) remains constant; otherwise, carcass fatness increases as dietary energy level increases (Bartov et al., 1974; Mabray and Waldroup, 1981; Skinner et al., 1992). Mabray and Waldroup (1981) noted four general nutritional factors that influence the degree of fatness in broilers, among which narrowing the C:P has been noted to decrease the deposition of body fat and an imbalance of amino acids may cause an increase in body fat.

PARTITIONING OF FEED ENERGY

The birds' nutrient requirement for the desired production level and the composition of feedstuffs to be used must be known to formulate a diet that can be utilized by different classes of poultry. The first consideration when formulating a ration is the energy content of the diet as the largest portion of the feed is devoted to satisfying the bird's energy requirement. Energy content in feedstuffs can be expressed as calories or joules of gross energy (GE), digestible energy (DE), metabolizable energy (ME), or net energy (NE) (McDonalde et al., 1995).

Gross energy (GE) represents the amount of heat released when a substance is completely oxidized in a bomb calorimetry, an d as such may not be a useful measure of utilizable energy be the animal. Digestible energy (DE) is the GE of the feed consumed minus fecal energy. However, fecal and urinary waste is voided together in birds, making it difficult to determine DE in poultry (McDonalde et al., 1995)

METABOLIZABLE ENERGY (ME): The apparent ME (AME), the most widely used measure of food energy for birds, is the difference of GE and energy contained in the excreta (fecal and urinary energy). True ME (TME) determination on the other hand requires the separation of the GE of the excreta of food origin from those of endogenous origin. TMEn is TME corrected for protein tissue growth or loss by adding to the excreta energy, the energy equivalent of the nitrogen retained or subtracting from it the energy equivalent of the nitrogen lost (NRC, 1994). However, this is relatively small for birds under maintenance conditions.

Currently the ME system of describing the energy concentration of poultry feeds is widely used to formulate rations for birds (NRC, 1994). However, variations in dietary proportions of fat, starch, and protein impact the efficiency of ME utilization which is one limitation of the ME system. The ME derived from fats > carbohydrates > proteins (Carew and Hill, 1964; Hoffmann and Schiemann, 1971; De Groote et al., 1971). De Groote (1973) showed that a system based on ME values underestimates the utilizable energy of fats and fat-rich feedstuffs and overestimates protein–rich feedstuffs (Pirgozliev and Rose, 1999).

NET ENERGY (NE): The proportion of energy in the feedstuff utilized for maintenance and production purposes is the net energy (NE) value of the feed. The NE is ME minus the energy lost as heat increment (HI) (NRC, 1994). The HI is an energy cost on feed that may serve to warm the body. HI is the heat produced due to inefficiencies of digestion and nutrient fermentation in the gut as well as heat produced due to metabolic processes in the body (MacLeod and Shannon, 1978; Boshouwers and Nicaaise, 1985). Heat production associated with environmental changes (Van Kampen et al., 1979; Meltzer, 1983) and due to quantity and quality of the different substates present in the feed (Sturkie, 1986) as well as external factors such as heat distress (Teeter et al., 1986) may also contribute to HI.

Net energy is used to meet the requirement for maintenance (NEm) and production (NEp). The NEm includes the energy needed to sustain life and to maintain body temperature and is lost as heat. Thus, the total heat production of the animal is HI plus NEm. If the supply of NE is greater than the energy required for maintenance, it is used for NEp, including accretion of bodily tissues. In 0-21 days of age chicks, it has been reported that about 84% of the ME is available as NE, although animal factors and/or type of feedstuff can impact this proportion (Sturkie, 1986).

Farrell (1974) feeding a diet of 18.4 kJ GE noted that about 27% of the energy was lost in the feces and urine (Figure 2). Wiernusz (1994) reported that of the total feed energy only 38% is retained by the bird where as 34% is lost as heat and another 28% is lost as excreta (Feces and urine). Similarly Beker (1996) reported that maintenance requirement accounts for ~ 36% of the metabolizable energy of the feed (Table 1) where as energy for gain and activity is estimated to be 65 and 19%, respectively.

Mittelstaedt et al. (1987) have demonstrated that birds raised on equivalent supplemental ME quanta, (derived from different sources), exhibited differences in energy gain. The authors reported similar amounts of protein gain with differing fat retention between the treatments. Care was taken to maintain a similar ratio of indispensable amino acid:ME ratio. Substrates (soybean oil, corn starch, or gelatin) were added to a basal ration, which was pair fed to growing broilers. The results showed that birds fed supplemental energy as either soybean oil or corn -starch had greater energy (30 % and 16 %) and fat gain (112% and 85%) than birds supplemented with gelatin (Mittelstaedt et al., 1987). The study also highlighted the effect of substrates on energetic efficiency and showed that ME is unlikely to accurately predict bird NE unless ingredients have homogeneous composition in terms of carbohydrate, lipid, and protein (Mittelstaedt et al., 1987).

Similar to the finding of Mittelstaedt et al., (1987), a lack of ME to accurately predict bird NE was shown in a broiler study with birds fed six feeds containing equivalent amount of vegetable fat, protein, and starch concentrations formulated to meet the bird's nutritional requirement (Collier et al., 1996). The authors failed to note differences in apparent ME, but reported differences in both energy retention and feed conversion ratio. Similar result has been noted in a related study conducted with swine fed two starch diets having similar ileal digestibility, that indicated differences in net utilization of the diets (Meulen et al., 1997). This was suggested to be partly due to differences in the lactate and volatile fatty acids production in the gut by bacterial fermentation (Meulen et al., 1997). Also, Muramatsu et al. (1994) in a study with germ-

free and conventional chickens fed an equivalent dietary ME intake reported a 16 % less NE for conventional chickens.

Other studies also failed to provide similar growth performances when fed diets with similar level ME (MacLeod et al., 1998). This suggests that HI of feeds or energy associated with absorption, excretion and secretion likely differed among the isocaloric diets, thus resulting in different NE. Pirgozliev et al. (2001) fed female Cobb broiler chickens 12 isoenergetic diets made of 6 different wheat cultivars having nearly equal proximate nutrient composition, did not find any differences in the apparent ME corrected for nitrogen (AMEn) consumption of the wheat samples. However, they observed a difference in bird carcass energy retention among the wheat cultivars, and attributed it to a large difference in efficiency of utilization of the AMEn in wheat cultivars for energy retention.

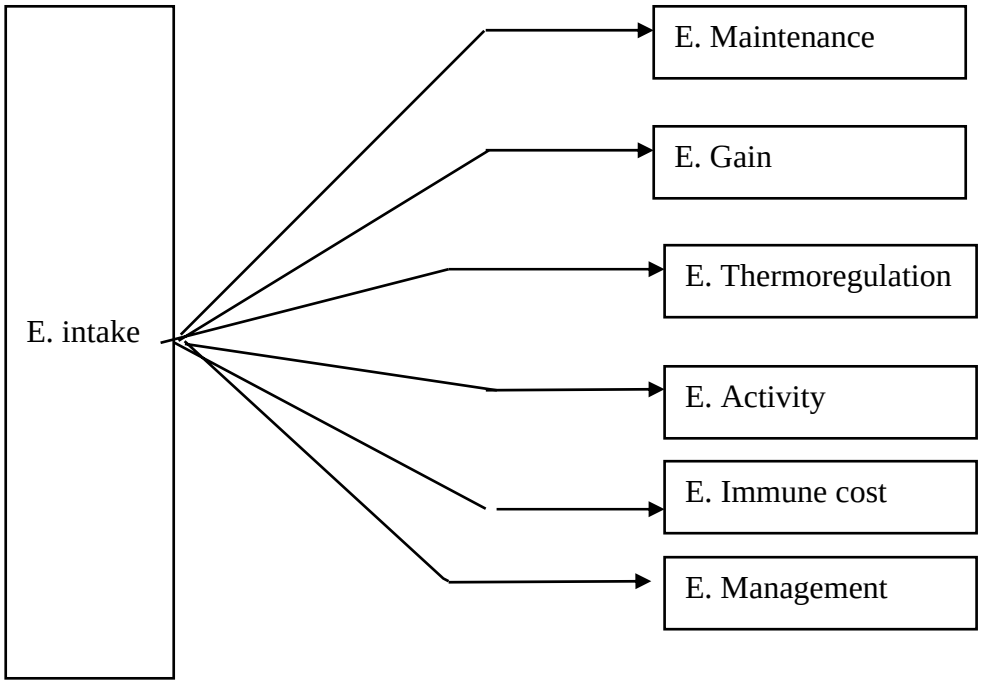

Figure 1. Energy (E) partitioning Scheme for broilers

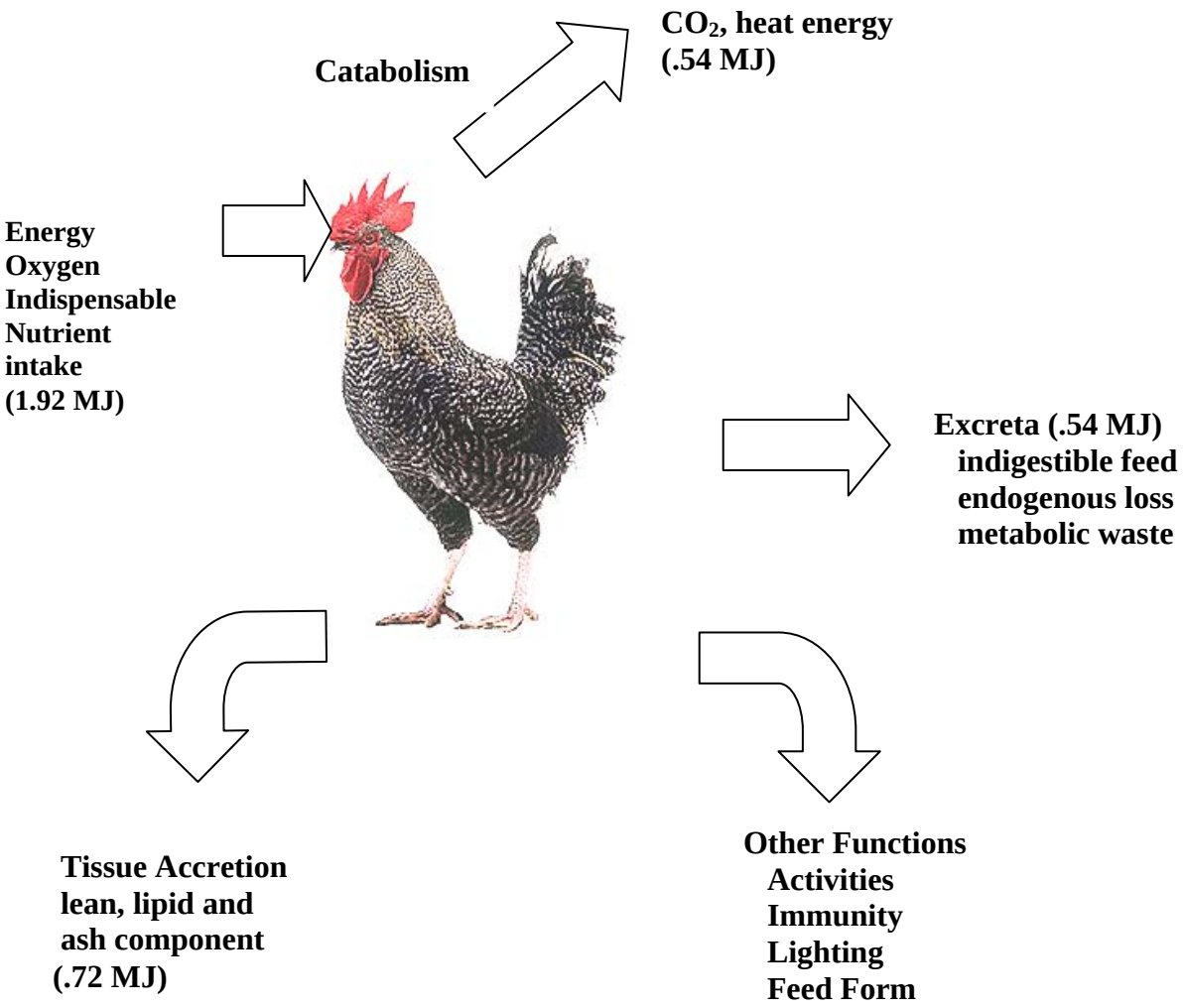

Figure 2. Energy partitioning in broiler chicken (Farrel, 1974)

Table1. Partitioning energy in broiler chickens

Age (d)	BWT (g)	MEn	Maintenance	E Gain	Activity	BMR
				kcal		
7	201	505	118	387	20	99
14	481	1733	541	1192	269	272
21	860	3691	1225	2466	680	545
28	1314	6306	2145	4161	1208	938
35	1819	9503	3291	6212	1833	1458
42	2348	13210	4668	8542	2564	2104

Source: Beker (2003)

EFFICIENCY OF FEED CONVERSION IN BROILERS

GENETICS: Over the last decades the broiler industry realized vast improvements in efficiency of production due to advances in genetics, nutrition and improved management. The trait with the greatest effect on profitability in the broiler industry is feed conversion ratio, which is a measure of the productivity of an animal and is defined as the ratio of feed consumed to weight gained. The lower feed conversion ratio, the better the efficiency. Broilers effectively convert feed to meat, with a possible feed conversion ratio of l.80 to l.90 (Cobb Vantress, 2004).

The modern meat-type chicken has been bred to gain weight at a rapid rate. Lacy (2000) reported that 4.5 kg of feed was required to produce a 1.4 kg broiler five decades ago; while the same amount of feed can raise a nearly 2.3 kg broiler in the present days. Chambers et al.(1981) reported that at 47 days of age, a broiler raised in 1978 weighed 2.3 times as much as a broiler raised in 1957. Also at 42 days of age, feed conversion ratio of a broiler raised in 1991 was 30% lower than that of one grown in 1957 (Havenstein et al., 1994a). Lacy (2000) also noted a 10% improvement in feed conversion of broilers during the last 30 years.

About 85 to 90% of the increase in poultry production relate to genetic improvement (Sherwood, 1977; Havenstein et al., 1994). This was also noted in a study that showed a genetically selected broiler in1991 weighed 3.7, 4.2, 3.9, and 3.5 times more than a non-selected broiler raised in 1957 at 21, 42, 56, and 76 days, respectively (Havenstein et al., 1994a). Further comparisons of growth when the birds were reared on the same 1991 diet also showed that the selected broiler weighed 3.0, 3.4, 3.1, and 2.9 higher than the non- selected one. Havenstein et al (1994a), compared the growth of two

different broiler strains, found that the fast growing broiler Arbor Acres broiler (AA) weighed 4.2 and 3.9 higher at 42 and 56 days respectively than the Athens-Canadian Random bred Control broiler (ACRBC), a strain which had not undergone intentional selection since its establishment in 1957. The changes occurring in broiler BW over 15 years, has reduced the broiler market age by nearly one day per year (Marks, 1991).

Gonzales et al. (1998) compared the growth performance of seven contemporary broiler strains (Cobb 500; Arbor Acres; Avian Farms; ISA; Hubbard-Peterson; Ross; and Label Rouge) fed the same diet, at 42-days of age they observed that the Label Rouge, a Naked Neck strain with no genetic selection on growth rate traits had nearly half the weight of either one of the modern fast growing broiler strains. Buzingo (2003) reported that the 1999 broiler had greater body weight, lower feed intake, and improved feed conversion than the 1994 broiler at the same age (Table 2).

Table 2. Improvements in feed conversion ratio (FCR) of the 1994 and 1999 broiler at equalized body weight

	Feed Intake			FCR		
Live weight	1994 (g)	1999 (g)	Improvement (%)	1994 (g/g)	1999 (g/g)	Improvement
250	272.55	249.18	9.35	1.090	0.997	9.35
500	619.13	599.86	3.21	1.238	1.20	3.17
1000	1428.6	1391.92	2.64	1.429	1.392	2.66
1500	2393.43	2304.89	3.84	1.596	1.537	3.84
2000	3513.37	3338.7	5.23	1.757	1.669	5.27
2500	4788.51	4493.56	6.56	1.915	1.797	6.57
3000	6218.84	5769.26	7.79	2.073	1.923	7.79
3500	7804.37	7165.87	8.91	2.23	2.047	8.94

GENETIC SELECTION ON CARCASS COMPOSITION: Selection of meat-type birds focuses not only on increasing growth, but also on the improvement of carcass quality, that can be achieved through alterations in body composition that favor higher yields of breast meat and lower abdominal fat. As a high heritable trait, Le Bihan-Duval et al. (1999) noted that body composition can be significantly improved by selection.

Chambers et al. (1981) compared the carcass of broilers raised in 1978 to those raised in 1957, and noted that the earlier had carcass weight nearly twice in percentage of legs and thighs, but lower percentage of wings and less nitrogen and ash concentrations of carcass compared with the latter. Similar significant changes in carcass composition in modern broilers were observed by Havenstein et al. (1994b) who reported that the 1991 Arbor Acer (AA) broiler strains had 6 to 7 % greater hot carcass weight yield, 4% higher yield of saddle and legs when taken as percentage of live body weight, and 3% higher in yield of total breast meat, compared with ACRCB raised in 1957. A higher percentage of fat pads and carcass fat, but lower size of heart and lung were also noted in AA broilers produced in 1991 compared with the ACRCB raised in 1957.

Different carcass components do not necessarily grow at the same rate. Lesson and Perreault (1992) observed linear growth in body weight, and a quadratic increase of the eviscerated carcass, deboned breast meat and legs. The same authors also reported that moisture and fat content of the eviscerated carcass increased with age, whereas protein content decreased. Such changes percentage of protein and fat in eviscerated carcass recorded from broilers over the years (44.9 and 39.4 % in 1969; 46.2 and 45.6 % in 1980; and 45.7 and 47.4% in 1992; for protein and fat, respectively; Lesson and Perreault, 1992) suggest that genetic selection has lowered changes in broiler protein

carcass when compared to changes in fat. Thus, it appears that a better improvement in bird growth rate was achieved at the expense of meat quality (lean tissue accretion) over years broiler selection. Nonetheless, considerations of the low percentage values of wings on eviscerated weight recorded along the years (13.5%, 12.9 %, and 11.3% in 1969, 1980, and 1991, respectively), in contrast to the continuous increase in breast yield (23.1%, 26.6%, and 31.3 %, in 31.7% in 1950, 1973, and 1992, respectively) suggest that there has been a continuous increased yield of the economically valuable parts of the broiler carcass over the years (Moran and Orr, 1969; Leeson and Perreault, 1992).

NUTRITION: Carbohydrate, fat and protein are the energy yielding organic nutrients. Carbohydrates contain carbon, hydrogen and oxygen, and range from simple sugars such as glucose to polymers like starch and cellulose. Carbohydrates are the main repository of photosynthetic energy in plants and comprise 50-80% of the dry matter of cereals which form the bulk of broiler feeds (McDonald, et al., 1995). The nutritive characteristics of carbohydrate for animal feeding are variable, depending upon the type of carbohydrate polymer and linkages. Many carbohydrates are hydrolyzed in the gut, yielding mainly glucose or other simple sugars which are readily converted to glucose in the liver (Murray, et al., 1993).

The largest part of practical broiler diets is comprised of carbohydrate of which starch is the major contributor. Starch digestion in birds is accomplished by the action of pancreatic amylase. The bird's ability to alter amylase level to suit the starch content of the feed may explain why starch digestibility is considerably higher in birds than in other animals (Murray, et al., 1993).

Avian species derive less ME from fibrous ingredients than mammals. Likewise, birds utilize poorly both lactose and galactose (Rutter et al., 1953). Thus, although utilized well by poultry, dextrose has a lower ME yield than either sucrose or starch. With experimental diets containing intact proteins (e.g., casein or soybean), feed consumption and growth rates are usually best when dextrose is used as the carbohydrate source (Baker, 1987). Dextrose, however, is reducing sugar and, as such, is very reactive with free amino groups. These Maillard type reactions are facilitated by heat and humidity, thus, casein dextrose diets for chicks should be stored under refrigeration. All metabolic pathways studied in mammals appear to be operative also in avian forms, although in several cases there are differences in the relative contribution of a given pathway to the overall energy requirements of a specific tissue or even to the organism as a whole. The production of pentoses, three-carbon phosphates, NADPH, and CO2 by this shunt pathway makes available substrates for a wide variety of reactions, including pentoses for nucleotide and nucleic acid synthesis, three-carbon phosphates for recombination leading to glucose-6-phosphate, and reduced NADP for lipogenesis and steroid synthesis (Goodridge, 1968b).

The major fats in the diet of birds are triacylglycerols and, to a lesser extent phospholipids. The main site of fat deposition in the animal body is adipose tissue that serves as energy storage as triglycerides. Fat contains the highest amount of energy per unit weight compared to other nutrients (Nir and Keren-Zvi, 1988).

Chickens synthesize most of their fatty acids (from glucose or acetate) in the liver, as is also the case in humans. In contrast, in pigs most of the fatty acid synthesis occurs in adipose tissue, and in rats the site of fatty synthesis equally divided between liver and

adipose tissue (Leville et al., 1975). Likewise the activity of lipid transfer protein in chickens, as in humans, is at least seven times higher than in rats (Kato et al., 1989; Nishida et al., 1990). Lipid transfer protein functions to transport cholesterol esters as well as triglycerides. Synergism exists in ME yields when unsaturated and saturated fat sources are combined for poultry. Thus, the ME value of corn oil is 8,390 kcal/kg when added to a diet containing predominantly unsaturated fat, but it increases to 9,380 kcal/kg when added to a diet containing most of its fat in saturated form (Leeson et al., 1996). The capacity of chicks to utilize fat for energy also increases with age of the bird. Sell et al., (1985) demonstrated that with both tallow and an animal-vegetable blend, the ME yield in young turkeys increased by over 25% with age from 2 to 8 week. Kaongole and March (1980) and Sell et al. (1985) attributed the age related improvement in lipid utilization to a fivefold increase in fatty acid binding protein in the gut between 2 and 8 week of age. However, it appears that no such age-related changes in nutrient utilization occur with protein or carbohydrates (Baker, 1991).

Changes in the size of adipose tissues may not be accompanied by appreciable changes in inter- or intramuscular fat content in the chicken (Grey et al., 1983; Ricard, Leclercq and Touraille, 1983; Becker et al., 1984; Cahner, Nitsan and Nir, 1986). The skin and skeleton also contain appreciable amounts of fat (Essary and young, 1977; Hakansson, Eriksson and Svensson, 1978). The estimation of fat located in adipose tissues can be done by determining the weight of abdominal fat pad (AFP) since fat depots in the chicken body are positively correlated with AFP (Becker et al., 1979; Cherry et al., 1984).

Young broilers may contain 150-200 total lipids/kg BW (Scheele et al., 1981; Griffin and Whithead, 1982; Leenstra, 1982). Evans (1977) estimated that in poultry, adipose tissues and skin may store over 85% of the body triglycerides. In broiler chicks divergently selected for high or low AFP, it was estimated that the increment obtained in the fat line was mainly due to an increase in adipose tissues (Chaner, Nitsan and Nir, 1986). In a study, where five adipose tissues were dissected quantitatively: (1) AEP, from the gizzard down to the cloaca; (2) gizzard (GAT), adhering to the gizzard; (3) sartorial (SAT), from both thighs; (4) neck (NAT), from the shoulder level p to the head, and (5) mesenteric (MAT), adhering to the mesentery and to the intestine from the pylorus to the colon, the adipose tissues relative weight was about 20-40 g/kg live body weight; that of the liver, skin, feathers, and skeleton was 25, 65, 45, 200 g/kg respectively (Nir, Nitsan and Keren-zvi(1983).

Diet composition may directly or indirectly affect adipose tissue growth and fat deposition. An important factor is the effect of diet composition and texture on food intake during ad libitum feeding. Dietary manipulations favoring energy intake such as pelleting or changes in energy concentration are accompanied by an increase in fatness (Fisher and Wilson, 1974; Picard, 1981; Pesti et al., 1983; Laclercq, 1986).

Energy density, protein concentration, energy to protein ratio (E:P) and fat concentration, considered to be the main dietary factors that have been studied extensively (MacLeod, 1988; Fisher, 1984; Leenstra, 1986). The E:P is considered as the most important regulators of food intake and of carcass fat content. A narrow E:P ratio is accompanied by a reduction in body fat deposition (Fraps , 1943; Guillaume and Summers, 1970; Bartov et al., 1974; Bartov, 1979; Jackson et al., 1982). The carcass

lipid concentration is more closely correlated with ME density (r =0.69) than with the E:P ratio (r = 0.47). The fatty acid pattern of adipose tissues and carcass is determined by the relative contributions of lipogenesis and dietary fat. Linoleic and Linolenic acids are not synthesized by the bird and their presence in adipose tissues depends on their presence in the diet. Bartov and Bornstein (1976) suggested that the ratio of saturated plus monoenoic fatty acids to polyenoic fatty acids could be used as an index of fat synthesis from carbohydrates, a wider ratio indicating more lipogeneis.

There is increased consumer demand for leaner products presumably due to health concerns with fat rich foods (NACNE, 1983;CMAFP, 1984; Jackson et al, 1982). Knowledge of metabolism of proteins and its relation with lipid, carbohydrate and energy metabolism is, therefore, of paramount importance in order to be able to produce leaner broiler products that meet the consumers demand.

Proteins are organic compounds which are constituents of all cells and are essential to sustain life. These compounds are formed by chains of amino acids linked together by peptide bonds. It is the order of these amino acids that determines the chemical, biological and physical characteristics of a specific protein. The molecular weight of proteins ranges from 5000 (Insulin) to 40 million (Tobaco mosaic virus) depending on the structure of the protein (Stenesh, 1998). Proteins also serve as regulators of metabolism (enzymes and hormones), structural components of membranes, muscles and connective tissues, transport molecules, osmoregulators, and body defence through immunoglobulins (Dukes, 1993).

Animal factor (genetics) together with dietary factors plays an important role on adipose tissue weight and fat concentration at various sites (Nir et al., 1983). They

reported that feed intake was higher in the high fat (HF) than in the low fat (LF) chickens and it was maximal when intermediate protein (IP) diet was fed and slightly decreased when the HP or LP diet was fed. Feed utilization was improved parallel to the increase in dietary protein concentration in the LF line. It seems therefore, that the HF and LF lines differ in their protein requirements for optimal growth and feed utilization. This agrees with the suggestions of Leclercq (1983), that although the lean lines utilize dietary protein more efficiently, their requirements are higher than those of the fat line, and therefore low protein diets are more detrimental to lean than to fat lines.

The higher sensitivity of lean chickens to a low protein diet agrees well with the work of Sorensen (1980), who demonstrated that selection for growth rate on a low protein diet resulted in selection for fatness. It was reported by Saunderson and Whitehead (1987) that lean birds oxidized significantly less of administered amino acids to CO_2 and excreted less carbon in the excreta than their fat counterparts. This could be due either to better protein utilization by the lean birds and/or to an excess of amino acids consumed by the fat line, due to a higher feed intake and lower requirement as compared to the lean line. It should be emphasized that protein utilization is better in lean than in fat chickens selected for high or low fatness (Leclercq et al., 1980; Whitehead and Griffin, 1984; Channer et al., 1986).

The relative weight of the adipose tissues was negatively related to the dietary protein concentration. The difference in adipose tissue weight between chickens fed low protein and intermediate protein diets were smaller in the high fat line than in the low fat line (Nir, Nitsan and Keren-zvi (1983). This is consistent with the improved feed

utilization observed in the low fat but not in the high fat lines when fed the intermediate protein versus the low protein diets.

ACTIVITY

Activity has been shown to impact energy utilization in poultry. Deighton and Hutchinson (1940) reported that heat dissipation varies continuously except when birds are completely motionless. Activities involving little exercise show minimal amounts of heat loss while rising to a standing position from sitting doubled energy expenditure (Deighton and Hutchinson, 1940). However, over a 24 hour period this amounts to only a 0.6% increase. Heat production in the standing position was approximately 42% above that in the sitting position (DeShazer et al., 1970). Ota (1967) reported an average reduction in day to night total heat production for White Leghorn layer and Rhode Island Red was approximately 30% at temperatures between -4 and 32 ^{0}C. They suggested the use of laying cages for egg production in order to restrict activity, and this stimulated a great deal of research in the rearing of broilers in cages in order to make best use of the dietary energy for growth.

Being able to control activity in broiler chickens may improve welfare in current production systems. Firstly, increased activity during the beginning of the growth period can reduce later lameness. Secondly, improved agility due to better leg health may improve litter and reduce skin lesions on both the feet, hocks and breast of the birds. Thirdly, being able to reduce activity during broiler harvesting may reduce catching injuries and improve welfare as well as yield. Indeed, much attention has been paid to activity in broiler chickens, in particular attempts to increase activity early in the growing period. Light intensity has been shown to affect activity in broiler chickens but past

studies have mostly focused on constant light intensities and static responses of the broiler chicken (Boshouwers, and Nicaise, 1987).

MANAGERIAL FACTORS AFFECTING FEED CONVERSION

TEMPERATURE: Birds are homeotherms, thus maintain a relatively constant body temperature regardless of the temperature of their environment. Higher or lower ambient temperature impact feed consumption, body weight gain and feed conversion. At higher ambient temperatures, the birds heat load is increased due to the environmental heat gain and the energy cost associated with activation of metabolic processes required for heat dissipation (Meltzer, 1987). Adaptations to increase heat dissipation in birds include postural adjustments (Baldwin, 1974), vasodilation of extremities (Nolan et al., 1978) and water intake (Farrell and Swain, 1977). On the other hand, in cold environment, broilers increased feed intake, and part of the additional calorie intake will be used to sustain normal body temperature, and such increase in carlie used to keep the body warm will adversely impact bird efficiency. High ambient temperatures also decrease growth rate, feed efficiency and breast yield of broilers (Cahaner and Leenastra, 1992). Hence, optimum temperatures allow broilers to efficiently use nutrients for growth.

VENTILATION: Ventilation and temperature are interrelated. Most often, increasing ventilation results in lower temperatures in a poultry house. Ammonia and other toxic gases build up in under ventilated broiler houses during the cooler months of the year. Atmospheric NH_3 in poultry facilities, though rarely studied directly, has long been recognized as a significant environmental problem in both laying hen and broiler grow-out facilities (Reece et al, 1981). In practice, poultry are often exposed to 50 ppm NH_3. This concentration may rise markedly in poorly ventilated houses where ammonia

concentration may exceed 200 PPM (Carlile**,** 1984), which may result lowered performance of the birds.

WATER QUALITY: Water is one of the vital nutrients mostly overlooked in the poultry production. Clean, fresh water is important for better feed conversion and performance of birds. Broiler performance on contaminated water supplies is below average. Studies indicate that feed consumption and body weight gain were depressed under elevated ambient temperature when access to water is inadequate (Harris et al, 1974). Birds offered cool drinking water during heat stress were reported to have greater survivability (Fox, 1951).

LIGHT: Broiler chickens normally do not eat during darkness, as long as this period does not extend for more than about 12 h (Savory, 1979). Therefore, it is assumed that feed intakes, as well as growth, are maximal for broilers that are reared in (nearly) continuous illumination. However, several studies showed that alternative lighting schedules, such as increasing or intermittent lighting schedules, improve body weight and feed conversion, and reduce leg problems and mortality (Ketelaars *et al*.,1986; Classen *et al*., 1991; Blair *et al*., 1993; Clarke *et al*.,1993). Nevertheless, published papers concerning intermittent lighting schedules on broiler performance are inconsistent.

Light levels in the broiler house can influence feed conversion. Relatively bright lighting (one to two foot candles) stimulates chick activity and helps them locate feed and water. After 10 to 14 days of age, light levels can gradually be reduced to a level of approximately 0.5 foot candles in the darkest areas. Low light levels such as this calm the broilers and reduce bird activity resulting in better weight gain (Buyse et al., 1994; Classen and Riddell, 1989).

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CHAPTER III

LIGHTING EFFECTS ON BROILER FEED CONVERSION AND ON METABOLIC FACTORS ASSOCIATED WITH ENERGETIC EFFICIENCY

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ABSTRACT An experiment was conducted using 7 to 50 day old male broilers to evaluate the influence of three lighting programs: 23 h of light and 1 h of dark (23L: 1D), 12 h of light and 12 h of dark (12L: 12D), and 1 h light followed by 1 h of dark (1L: 1D). Traits measured included BW, body weight gain, feed intake, and feed conversion and body composition partitioned into protein, fat, water and ash gain; Oxygen consumption, carbon dioxide production (CO_2), C loss as CO_2 carbon per feed carbon consumed energetic efficiency and the coefficient to convert live body mass to metabolic body size. Gas exchange was used to quantify HP with data examined as complete and light versus dark phases. Effects of lighting program on weight gain were significant, but also interacted with age ($P < 0.01$). Upon completion of the finisher period, birds exposed to 12L: 12D showed less feed consumption, increased live weight gain, and improved FCR ($P < 0.05$). Likewise, heat production was lowered and efficiency of ME utilization for growth improved ($P < 0.05$) in birds reared on 12L:12D. Body composition (g of gain) did not differ ($P > 0.05$) among the three lighting programs in the starter phase, whereas there was higher ($P < 0.05$) protein accretion for birds on 12L:12D in the grower and finisher phases compared to birds on 1L:1D. Fat to protein ratio increased with age curvilinearly but was not influenced by lighting program. The Effective Caloric Value (ECV) was the highest ($P < 0.05$) for the 12L:12D lighting treatment and was better ($P < 0.05$) for the 12L:12D in the grower, and finisher phases. Carbon loss, expressed as % CO_2 carbon produced per feed carbon consumed were also improved ($P < 0.05$) for the 12L:12D at 61% for the 1L:1D and 57% for the 23L:1D and 53% for the 12L:12D programs respectively. Energetic efficiency decreased with age, was not influenced by lighting in the starter phase but was highest for the 12L:12D lighting treatments ($P <$

0.05) in the grower and finisher phases. Beneficial lighting program effects for the 12L: 12D treatment are possibly mediated by feed intake extent and reduced energy expenditure for activity. The coefficient to convert live body mass to metabolic body size averaged 0.67, similar to classic work by reported by Brody (1945).

Key words: Lighting program, broiler, feed efficiency, and metabolic efficiency

INTRODUCTION

The beneficial effects of lighting program (defined as the provision of light duration) have long been noted for broilers (Moore, 1957). Since that time numerous studies and programs have been implemented to enhance broiler production and to moderate a myriad of metabolic-physiologic concerns such as feed conversion and energy metabolism (Apeldorn et al., 1999; Ohtani and Leeson, 2000), sudden death syndrome (Ononiwu et al, 1979), leg problems (Riddell, 1975), performance and yields (Renden et al., 1991). However, the precise metabolic effects of lighting program on broiler metabolism as energy expenditure and tissue accretion efficiency are largely unknown. Additional benefits include such diverse factors as ascites reduction fewer leg disorders and reduced morbidity among others. Lighting programs may be of increased importance as the genetic selection of broilers continues to produce larger birds at similar market age. Identification of lighting metabolic-physiologic effects may enable lighting programs to better match the desired need.

Historically poultry companies have utilized continuous light or 23L: 1D to allow for maximum feed consumption and growth rate (Renden et al., 1991). However, manipulation of the lighting program by either reduction of total hours of light (16L: 8D Robins et al., 1984) or intermittent schedules (1L: 3D; Buckland, 1975; Ononiwu et al., 1979; Wilson et al., 1984) has been reported to alleviate the incidence or severity of circulatory and leg disorders with slight or no loss of body weight at marketing. Classen and Riddell (1989) provided broilers 6L: 18D for the first 3 weeks of age and then increased the light period to 23L: 1D to 42 days, with reduction of Sudden Death Syndrome (SDS) and leg abnormalities and variable body weights.

Continuous or near continuous day lengths have generally been used for commercial broiler production as they allow uniform access to feed throughout the day (Classen; 1992a). This optimizes conditions for feed intake and growth by exploiting the birds' feeding behavior (Gordon, 1994). Broilers may be considered 'nibblers' rather than 'meal-eaters', as they consume feed in small quantities at regular intervals throughout the day (Masic et al., 1974; Savory, 1976). Savory (1976) reported that broilers receiving continuous light consumed 3-6% of their total daily feed intake per hour. Savory (1976) also reported that reducing day length by providing a scotoperiod (dark phase) modifies feeding behavior and may restrict feeding behavior to the photoperiod. Near continuous light programs encourage nibbling and reduce the opportunity for rest and sleep, which tends to be disturbed by companion birds walking to the feeders (Gordon, 1994). Murphy and Preston (1988) measured eating, drinking, standing and sitting activity with broilers housed under continuous lighting, reported that although 64% of their time was spent sitting, 60% of all sitting bouts were less than one minute in duration and only 4% were longer than three minutes.

Intermittent lighting programs (IL) have been reported to improve FCR and reduce abdominal fat content relative to broilers raised under nearly continuous lighting (Buyse et al., 1994, 1996). According to Barott and Pringle (1951), chicks will consume all the feed they desire within 1 hr and empty their crops sufficiently to eat again after 3 to 4 hr. Gore et al. (1969) concluded that an adequate dark period of inactivity following feeding plays a dominant role in broiler growth. Additionally, during the dark period of each dark-light cycle, heat production is markedly decreased (Buyse et al., 1994). Ohtani and Leeson (2000) reported that IL chickens exhibited a higher ME intake at 6 and 8 wk of age than

did CL chickens. Total heat production for IL chickens was higher than for CL chickens, although heat production during the dark period was less than during the light period for IL chickens (Ohtani and Leeson, 2000). Apeldoorn et al., (1999) found that intermittent lighting schedule induced improved feed conversion, higher metabolizability of the diet, and lower physical activity compared to continuous lighting. Dixon (2001) reported an increase in heat production (kcal/kgBW/h) of 59.2, 50.5, 57.0, and 52.9% for birds weighing 0.925, 2.28, 4.53 and 5.06 kg respectively.

Effective caloric value (ECV), is the dietary caloric density (CD) necessary for broilers to achieve specific body weight (BW) and feed conversion ratio (FCR) combinations under standardized conditions (Mckinney and Teeter, 2004). Lighting program (Buyse et al., 1996; Ingram et al., 2000) is well known to impact BW and FCR. Though the precise mode of action by which such nonnutritive factors impact poultry performance is considered disjoint from nutrition in application, their use is critical for today's profitable poultry production enterprise. The basic percept of ration formulation programs is that ME_n values are generally independent of, for example, bird sex and age, however; its utilization for retention is reduced when heat production is elevated. Bird heat production is influenced by a myriad of factors including ration composition and tissue type synthesized (MacLeod, 1997), intermittent lighting (Ohtani and Leeson, 2000), and activity among others. Indeed, energy expenditure for activity has been suggested to be influenced by nonnutritive factors such as lighting (Ohtani and Leeson, 2000). Failure to account for variations in heat production, regardless of source, eventually has the net result of creating an uncertain ratio of ingested ME_n calories available for tissue accretion to dietary protein and other nutrients. Under fixed experimental conditions, where

nonnutritive factors impacting heat production are held constant, varying the calorie to protein ratio impacts BW and FCR (Sizemore and Siegel, 1993; Leeson et al., 1996; MacLeod, 1997). One might conversely anticipate that experimental variation of nonnutritive factors, with ration formulation held constant and BW and/or FCR changing, would be better expressed as a variant of ME_n that more closely represents feeding value as ability to achieve a specified BW and FCR. As such, the ECV system offers the opportunity to place an energy value upon light program.

Classical expression of avian energy requirements are made relative to metabolic body size raised to the 0.67 power (Brody, 1945). However, such measures are referenced to mature birds with a minimal feed restriction of 36 hours. Such restrictions are inappropriate for young growing avian species. Yet data are transformed to metabolic body size independent of age.

The experiment reported herein was conducted to evaluate the effects of lighting programs on broiler feed consumption, body weight gain, body composition as water, protein, fat and ash; dietary calorie need per gram of live gain, heat production by indirect calorimetry, ration net energy for gain and energy cost of lean and lipid accretion as well as the coefficient to convert live body mass to metabolic body size.

MATERIALS AND METHODS

Three hundred broilers (Cobb x Cobb) were attained at hatch and reared to 7 days of age in floor pens with wood shavings litter. Birds were fed a broiler starter ration from hatching to 21 d of age, a broiler grower ration from 22 to 35 d of age, and a broiler finisher diet to the end of the experiment. The ingredients used in the diets and the calculated analyses are shown in Table 1. The lighting programs (23L:1D; 12L:12D; and

1L:1D) were applied starting at 7 d of age. On day 7, chicks were weighed, wing banded, and randomly assigned to 36 metabolic chambers housed in three environmentally, controlled rooms (12 chambers in a room) as described by Wiernusz and Teeter, 1993 and Belay and Teeter, 1993. Lights were off daily from 2300 to 2400 for the 23L:1D, from 1800 to 0600 for 12L: 12D and on every other hour starting at 2300 hr for the 1L: 1D. Feed and water were provided for ad libitum consumption, feed intake and live weight were recorded on fed and following 12 h of fasting at the beginning and end of each phase.

An indirect open circuit calorimeter was used for the determination of heat production by the chickens. Oxygen consumption and carbon dioxide production were continuously monitored for the entire duration of the experiment. Concentrations of O_2 and CO_2 entering and exiting the calorimetry chambers were recorded two times per hour for the smaller chambers and three times per hour for the larger chambers using an Allen-Bradly data acquisition system. Oxygen consumption and carbon dioxide production were estimated as the difference between incoming and outgoing chamber gasses multiplied by the chamber flow rates. Air flow rates were 3388, 6111, and 10153 ml/min for 7, 21, and 35 days old birds respectively. The equation of Brouwer (1965) was used to estimate heat production (kJ/h) from liters of Oxygen consumed and carbon dioxide produced: (HP=16.18 X O2 consumed + 5.02 X CO2 produced).

Upon completion of the starter, grower and finisher phases of the study, a representative sample of birds were selected, at random weighed, humanely euthanatized via CO_2 asphyxiation, double bagged in polyethylene bags, and frozen at -20C until further analysis was performed according to procedure described by Wiernusz (1994).

Upon thawing, lean and fat mass, as well skeletal mass and density were estimated using DEXA (Hologic QDR 4500 Elite) according to McKinney and Teeter (2004) as follows:

BirdWater(g) =(5.79504) + (0.76994*Fatg_1)+ (-0.00003797*Fatg_2)+ (0.68501*Lean_1) + (-0.00001373*Lean_2) + (-0.00015077*LeanFatg_1) + (2.43437E-1*LeanFatg_2)

BirdProtein(g) =(-.13349) + (0.1119*Fatg_1)+ 0.00003567*Fatg_2) + (0.18308*Lean_1) + (-0.00000370*Lean_2) + (0.00004728*LeanFatg_1) + (-1.252E-1*LeanFatg_2)

BirdFat (g) =(-5.6813) + (0.03129*Fatg_1)+(0.00006536*Fatg_2) + (0.10041*Lean_1) + (0.00002336*Lean_2) + (0.000096*LeanFatg_1) + (-1.2042E-1*LeanFatg_2)

BirdAsh (g) = (-1.6675) + (0.01579*BMC_1) + (0.02658*Lean_1) + (0.02434*Fatg_1) + (-0.00000395*LeanBMC_1) + (-0.00000254*FatgBMC_1) + (0.00000144*LeanFatg_1)

Effective caloric value (ECV), defined as dietary caloric density (CD) necessary for broilers to achieve specific body weight and feed conversion ratio (FCR) combinations under standardized conditions (McKinney and Teeter, 2004) was calculated for each treatment as:

CD=7017.65491 + (1.3773*BWT) - (0.00009006*BWT_2)+((5.247565E- 8)*BWT_3) - (5200.87308*CFCR)+(1566.92696*CFCR*CFCR)-0.75909*BWT*CFCR))

The energy retained in the tissue is calculated from the sum of protein and fat energy gain as bird fat (g) x 9.31kcal/g + bird protein (g) x 5.65 kcal/g . Feed carbon and nitrogen content was determined using an automated carbon-nitrogen analyzer (LECO CN-2000, LECO corp., St. Joseph, MI). Carbon released as carbon dioxide was summarized for the period as the sum of the daily CO_2 production and converted to grams carbon using the equation: (CO_2 production (L) / 22.4 moles L) x .2727 x 12 / Carbon consumption.

Dietary calorie per gram gain was calculated as (bird fat (g) x 9.31kcal/g. + bird protein(g) x 5.65 kcal/g)/bwt. Energetic efficiency was calculated as retained energy/MEI.

Statistical Analysis

A randomized complete block design was used in this study, as each lighting program was used in three rooms housing 20 environmentally controlled metabolic chambers. Data for all response variables were subjected to analysis of variance using the General Linear Models procedure of SAS (SAS Institute, 1985). When the F-test was significant, treatment means were separated using least significant difference (Steel and Torrie, 1960).

RESULTS AND DISCUSSION

The experiment was successfully conducted for the starter, grower and finisher phases. Results are presented in Tables 2 -10. As inference over the production cycle is desired for performance, energetics and body composition, data were initially transformed using $\log_{10}$ for all variables (Tables 2). Results lacking production phase x lighting treatment interaction are presented as their trial wise antilog value while variables with interaction were subsequently analyzed by production phase.

Data analysis in Table 2 examines log10 transformation for feed consumption, body weight and FCR for cumulative and with production period in a trial-wise manner. Phase x treatment interaction for all variables made it necessary to analyze results by production phase as contained in Table 3.

Results (Table 3) indicated that during the starter phase, birds exposed to the 1L:1D and 23L:12D programs consumed more feed ($P < 0.05$) than birds receiving

12L:12D at 559, and 553 vs 525g respectively. Body weight gain during the starter phase paralleled feed consumption with the 1L:1D program birds gaining more ($P < 0.05$) than birds on the 12L: 12D (340 vs 314g gain). During the grower phase, birds exposed to 12L:12D program consumed less feed than the 1L:1D lighting program but gained more live weight (962 vs 907g) than the 1L:1D treatment suggesting compensatory gain. This continued during the finisher phase, however, with 12L: 12D birds continuing to consume more feed (4,377g vs 4,135g) and exhibit more ($P < 0.05$) live weight gain than the 1L:1D program (1175 vs 1013g) while the 23L:1D program was intermediate, No differences in FCR occurred between lighting programs in the starter phase while FCR was improved ($P <.001$) for the 12L:12D during both the grower (1.42 vs 1.47 and 1.50) and finisher (1.68 vs 1.76 and 1.82) periods. Bird body weight gain was the least for 1L:1D lighting treatment both during the grower and finisher phases. Results suggest that birds on the 1L:1D may have either spent more energy on activity compared to birds on the other two lighting treatments or did not adequately adjust feed consumption rate during lighted period as feed consumption was reduced ($P < 0.05$). Treatment by phase interaction suggests that lighting duration effects impact the birds differently for each age and must be considered when lighting program specifics are debated. Younger birds tolerate the 1L:1D lighting schedule better than either the 12L:12D or the 23L:1D lighting schedules.

The metabolizable energy intake of the birds on the 1L:1D lighting treatment (1764 kcal/g) in the starter and (6225 kcal/g) in the grower phases were higher ($P < 0.05$) than the 12L:12D and 23L:1D treatments both in the starter and grower phases but in the finisher phase birds on the 12L:12D treatment had ME intake (8335 kcal/kg) than both

the 1L:1D and 23L:1D lighting treatments (Table 9). Birds on the 12L: 12D lighting treatment gained more ($P < 0.05$) and produced less heat compared to birds on the 23L:1D and 1L:1D treatments during the grower phase presumably indicating less energy wastage for activity and better gain resulting in higher efficiency (Table 9) though dilution of maintenance energy cost as a proportion of energy intake may also play a role as these birds also consumed more feed.

Regression analysis was used by regressing the log10 of fasted bird heat production on the log10 BW to estimate the coefficient converting live mass to metabolic mass. Traditionally this has been accomplished using adult birds fasted for extensive periods and termed BMR (Brody, 1945). Application to young birds necessitates establishment of appropriate relationship. Work reported by Skinner Noble and Teeter (200) indicated that body temperature was stabilized at 12-6 h post feed restriction in contrast to the 36 h used by Brody. In this study, contrasting 12-18 h with 14-16 indicated similar HP suggesting that a constant metabolic state had been achieved. The term MBR is suggested as it represents young birds and showed feed restriction. The regression equation obtained was $y = 3.0 + \log BW \times 0.67$ ($R^2=0.88$, $P < 0.0001$). The exponent to convert live weight into metabolic body size for this population of male broilers is therefore, 0.67 which is an exact match of Brody's 1945 values. Based on this information, it would appear that the .67 coefficient may be applied to both immature and mature broilers.

Calculation of ECV according to Mckinney and Teeter (2004) yields results displayed in Table 4 for cumulative and with phase (interval) values. Lack of treatment x phase interaction for the interval value allows examination of results on a trial-wise basis.

The ECV for the 1L:1D (2974 kcal/kg) in the starter phase exhibited ($P < 0.05$) the highest value, where as, in the grower phase it was the group of birds on the 12L:12D lighting treatment (2916 kcal/kg) that showed the highest MEI ($P < 0.05$). There was no difference in MEI in the finisher phase. Interaction between treatment and phase necessitated that the cumulative data be analyzed by phase. The 12L:12D was superior to the other lighting program during the grower and finisher periods.

The ECV data (Table 4) represents the energy value needed to achieve equivalent live weight and FCR under the reference condition of McKinney and Teeter (2004). The data may be transformed into the number of MEn calories consumed by multiplying the ECV value times the feed consumption. Table 2 and 4 displays projected calorie consumption and caloric density for the various treatment groups as both Men and ECV.

Strict caloric density advantage, relative to the 23L:1D ascribed to lighting program and phase are displayed in Table 5. Though no differences were noted during the starter, pronounced advantage for the 12L:12D over the 23L:1D program was detected for the grower (122 kcal/kg ratio) and finisher (250 kcal/kg ratio) periods. These results are likely attributable to a combination of feed intake and activity results. Multiplying mean metabolic weight (((initial weight + final weight) / 2) x $BW^{.67}$) for each treatment times the maintenance energy requirement (102 kcal/kg $BW^{.67}$) x days on test and dividing by the energy (kcal) consumption as MEn or ECV yields the feed consumed for maintenance as a proportion of energy intake (Table 5).

Improved grams of tissue accretion are the ultimate goal, while percentages reflect tissue proportion they are not salable product. Body composition of birds for water, protein, fat and ash at the end of each phase is as shown in Table 6 in both grams

and percentage composition. Birds on the 1L:1D lighting program averaged 16.63, 9.31 and 2.3 % protein, fat and ash had higher ($P< 0.05$) proportions of protein, fat and ash than the other two lighting treatments. In the grower phase birds on the 12L:12D lighting treatments contained more grams ($P < 0.05$) protein and fat than the other two treatments where as no difference ($P > 0.05$) in protein and fat content was observed ($P > 0.05$) among the three lighting treatments n the finisher phase . Fat to protein ratio (Table 7 and Figure 2) increased ($P < 0.05$) with advance in age of the birds from .55 in starter phase to .70 and .91 in the grower and finisher phases respectively. There was no difference in fat to protein ratio within a phase between lighting groups.

Calorie content per gram of tissue body weight increased with bird age as shown in Table 8. There was no difference in calorie per gram of gain between the three lighting programs in the starter as well as finisher phases. In the grower phase however, birds on the 1L:1D program had a higher calorie content per gram of gain compared to the 12L:12D and 23L:1D (2.12 vs 2.07 and 2.09 kcal/g) respectively. The increased calorie requirement of birds on the 1L:1D lighting program over that of the other two treatments may be attributable to the increased heat production observed by the 1L:1D treatment presumably for the increased activity by the birds.

Table 9 summarizes MEn and ECV consumption, heat production, RE and efficiency of MEn and ECV for energy accretion. Heat production of (8 kcal/h) of birds on the 1L:1D lighting treatment (Table 9) was higher ($P < 0.05$) than the other two lighting treatments, both in the grower and finisher phases whereas the difference was only an order of magnitude in the starter phase. This may be interpreted as a higher heat

production due to activity by birds in the 1L:1D lighting treatment or elevated heat loss as maintenance was a higher proportion of consumption.

Averaged over the trial, efficiency of metabolizable energy use for the 3 light treatments was impacted by lighting program ($P < 0.05$) with the 12L:12D program differing from the other lighting programs, 0.62, 0.54 and 0.54 for the 12L:12D, 1L:1D and 23L:1D, respectively. Efficiency of metabolizable energy use for RE decreased with advance in age from an average of 0.79 efficiency in the starter phase to 0.52 in the grower phase and further lowered to 0.37 in the finisher phase birds. Lighting has no effect on efficiency in the starter phase. In the grower phase, efficiency was higher for the 12L:12D (0.54) and the 23L:1D had the least efficiency (0.49) treatments (Table 9). Efficiency of 0.45 for the 12L:12D treatment was the highest ($P < 0.05$) in the finisher phase followed by .32 and .35 for the 1L:1D and 23L:1D programs respectively. This may also be explained by the lowered heat production but improved gain (lowered heat production) of birds on the 12L:12D lighting treatments. Lower energy need per gram of gain (2.07 kcal/g) in the 12:L12D treatment versus 2.12 kcal/g for the 1L:1D treatment during the grower phase shows that birds maintained under this lighting program were energetically efficient (Table 10).

Effective caloric deviation from the 23L:1D lighting program taken as the standard was 20.26 and 28.23 kcal/kg for the 12L:12D and the 1L:1D lighting program in the starter phase respectively(Table 5) were not different ($P > 0.05$). However, in the grower phase ECV deviation for the 12L:12D and 1L:1D lighting programs (122.28 versus -43.1 kcal/g) differed ($P < 0.05$) relative to the 23L:1D treatment, respectively.

Further in the finisher phase, ECV for the 12L:12D and 1L:1D lighting programs (249.86 versus -75.08 kcal/g) was different ($P < 0.05$) relative to the 23L:1D treatment (Table 6).

Liters of CO_2 produced during the study increased to 1.197 liters for the 1L:1D lighting program while the 12L:12D birds produced just1.032 L. Carbon dioxide produced per carbon consumed (Table 10) declined with advance in age of the birds indicating that birds were metabolically more active at younger ages. There was lower ($P < 0.05$) CO2 production (L) for the 12L:12D lighting program than the 1L:1D and 23L:1D both in the grower (537 vs 601 and 587) and finisher (1032 vs 116 and 1077) phases. The higher CO_2 production was in line with the efficiencies observed. Efficiency was the least for the 1L:1D treatment which produced more CO_2 .

SUMMARY AND CONCLUSION

The lower energy need per unit gain for the 12L:12D reflects increased energetic efficiency. The impact of lighting was especially pronounced during grower-finisher phases. The 12L:12D program was superior to the 1L:1D or 23L:1D programs for ECV and performance as evidenced by better weight gain, FCR, less HP, higher ECV and higher energy retention. Further, the 12L:12D program is found to be environment friendly with less liters of CO2 release to the atmosphere by 1936 liters vs 2048 liters for the 1L:1D. Fossil fuel burning is said to be contributing to global warming through release of CO2 to the atmosphere. Reduced CO2 release from the poultry industry may be advantageous in that it contributes positively to the reduction in green house gasses. Furthermore retention of carbon in body tissue instead of loss to the atmosphere increases

biological efficiency of the birds in addition to the economic benefits that may be attained.

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Table 1. Percentage diet composition for rations utilized during the starter, grower and finisher periods for broilers reared under three lighting programs

Ingredients and content	Starter	Grower	Finisher
		(%)	
Corn	56.45	64.11	68.37
Soybean meal	36.36	29.28	24.05
Fat, vegetable	3.74	3.19	4.49
Calcium carbonate	1.59	1.42	1.15
Dicalcium phosphate	1.20	1.40	1.47
Salt	0.31	0.30	0.18
DL-Methionine	0.14	0.10	0.04
Copper sulfate	0.05	0.05	0.05
Vit. Premix[1]	0.05	0.05	0.04
Mineral Mix[2]	0.05	0.05	0.04
Lasalosid	0.05	0.05	0.05
Choline chloride	0.001	----	----
Calculated content			
Protein (N x 6.25)	22.800	20.01	17.79
ME, Kcal/kg	3095.4	3135.0	3267
Methionine	0.510	0.429	0.338
Lysine	1.288	1.078	0.920
Calcium	0.940	0.900	0.800
Total phosphorus	0.600	0.610	0.600

[1] Vitamin supplied the following per kilogram of diet: vitamin A, 38,500 IU; vitamin D3, 11,000 IU; vitamin E, 55 IU; vitamin B12, 0.066mg; riboflavin, 33 mg; niacin, 165 mg; d-panthotheenic acid, 55 mg; menadione, 11 mg; folic acid, 3.3 mg; pyridoxine, 13.75 mg; thiamine, 6.66 mg; d-biotin, 0.28 mg.

[2] Mineral mix supplied the following per kilogram of diet: manganese, 120 mg; zinc, 100 mg; copper, 10 mg; iodine, 2.5 mg; calcium, 135 mg.

Table 2. Log transformed interval and cumulative feed consumption, body weight gain and feed to gain ratio during the starter, grower, and finisher phases for broilers reared under three lighting programs[1]

		Variable					
		Interval Results[2]			Cumulative Results[3]		
Production Phase	Lighting program[4]	Feed Cons (g)	BW gain (g)	FCR (g:g)	Feed Cons (g)	BW (g)	FCR (g:g)
Starter	Starter						
(day 7-21)	12L:12D	419	314	1.34 [cd]	525	438	1.20
	1L:1D	454	341	1.33 [d]	559	465	1.20
	23L:1D	448	332	1.35 [d]	553	455	1.22
Grower							
(day 21-35)	12L:12D	1464	964	1.52 [c]	2,010	1422	1.42
	1L:1D	1498	908	1.65 [c]	2,038	1358	1.50
	23L:1D	1498	940	1.60 [c]	2,037	1391	1.47
Finisher							
(day 35- 50)	12L:12D	2363	1,188	2.03 [b]	4,377	2613	1.68
	1L:1D	2167	976	2.30 [a]	4,135	2290	1.82
	23L:1D	2193	1,028	2.17 [b]	4,240	2423	1.76
ANOVA	ANOVA						
Phase	2	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001
Treatment	2	0.3053	0.0113	0.0422	0.0004	0.0004	0.0002
Phase x Treatment	4	0.0053	0.0085	0.3501	0.00002	0.0002	0.0689

[a-c] Means in a column within a phase with common superscript do not differ (P > 0.05)

[1] Log transformation was performed on data to normalize the distribution over the production cycle. Statistical differences are per transformed data. reported means are the antilog of transformed lsmeans

[2] Interval covers the period 7-21, 21-35 and 35-50 days of age ; [3] Cumulative covers the period 1-21, 1-35 and 1-50 days of age ;

[4] Lighting program defined as 12L:12D=12 hours continuous light followed by 12 hours continuous dark; 1L:1D represents 1 h lighting followed by 1 h dark repeated throughout the day;23L:1D represents 23h of continuous light followed by 1 h dark each 24 h period

Table 3. Lighting program effects on interval and cumulative broiler feed consumption, body weight gain and feed to gain ratio for broilers reared under three lighting programs analyzed by phase[1]

		Interval Results[2]			Cumulative Results[3]		
Phase	Lighting program[4]	Feed Consumption[5] (g)	Body Weight Gain[6] (g)	FCR[7]	Feed Consumption[8] (g)	Body Weight (g)	FCR
Starter							
(day 7– 21)	12L:12D	419[b]	314[b]	1.34	525[b]	438[b]	1.20[a]
	1L:1D	453[a]	340[a]	1.33	559[a]	465[a]	1.20[a]
	23L:1D	447[a]	330[ab]	1.35	553[a]	455[ab]	1.22[a]
			Probability			Probability	
		0.0110	0.0406		0.0110	0.0432	.5451
Grower							
(day 21–35)	12L:12D	1460[a]	962[a]	1.52	2,010[b]	1420[a]	1.42[b]
	1L:1D	1497[a]	907[a]	1.65	2,038[a]	1358[b]	1.50[a]
	23L1:	1489[a]	935[a]	1.60	2,037[ab]	1388[ab]	1.47[a]
			Probability			Probability	
		0.7335	0.1773		0.7335	0.1173	.0119
Finisher							
(day 35-50)	12L:12D	2358[a]	1175[a]	2.03	4,377[a]	2608[a]	1.68[b]
	1L:1D	2161[b]	953[b]	2.30	4,135[c]	2280[b]	1.82[a]
	23L:1D	2185[bc]	11013[ab]	2.17	4,240[bc]	2414[bc]	1.76[a]
						Probability	
		0.0276	0.0434		0.0276	0.0027	.0240

[a-c] Means in a column within a phase with common superscript do not differ (P > 0.05)

[1] analyzed by phase due to phase by treatment interaction for log transformed values displayed in Table 2

[2] Interval covers the period 7-21 d of age in the starter, 21-35 d of age in the grower and 35-50 d of age in the finisher phase respectively

[3] Cumulative covers the period 1-21 d of age in the starter, 1-35 d of age in the grower and 1-50 d of age in the finisher phase respectively.

[4] Lighting program defined as 12L:12D=12 hours continuous light followed by 12 hours continuous dark; 1L:1D represents 1 h lighting followed by 1 h dark repeated throughout the day;23L:1D represents 23h of continuous light followed by 1 h dark each 24 h period

[5] Interval feed consumption calculated as feed offered to birds – feed remaining in feeder at completion of the phase

[6] Interval weight gain is calculated as body weight at the end of a phase – body weight at the beginning of a phase

[7] There was no phase by treatment interaction, analysis is shown in Table2.

Table 4. Lighting program effects on MEn and effective caloric values and consumption (kcal) 7-50 days of age partitioned into starter, grower and Finisher phases for broilers reared under three lighting programs [1, 2]

		Effective Caloric Value (kcal/kg)[3]					
Production Phase	Lighting program[4]	MEn (kcal/kg)	MEn consumption (kcal/kg)	Interval ECV [5] (kcal/kg)	Interval ECV Consumption[6]	Cumulative ECV (kcal/kg)	Cumulative ECV Consumption[8] (kcal)
Starter							
(day 7– 21)	12L:12D	3095	1625	2965 [bc]	1244 [c]	3228[a]	1695 [b]
	1L:1D		1732	2974 [a]	1249 [c]	3231 [a]	1808 [a]
	23L:1D		1715	2946 [ab]	1321 [c]	3205 [a]	1776 [a]
						Probability	
						0.6333	.0239
Grower							
(day 21–35)	12L:12D	3135	6290	2916 [bcd]	4265 [b]	3197 [a]	6434 [a]
	1L:1D		6370	2786 [ab]	4174 [b]	3032 [b]	6181 [a]
	23L:1D		6386	2840 [bcd]	4288 [b]	3072 [b]	6336 [a]
						Probability	
						0.0045	.2250
Finisher							
(day 35-50)	12L:12D	3267	14047	2827 [d]	6710 [a]	3313 [a]	14553 [a]
	1L:1D		13266	2675 [d]	6389 [a]	2994 [b]	12188 [b]
	23L:1D		13606	2746 [d]	6042 [a]	3064 [b]	13080 [b]
						Probability	
						0.0017	
ANOVA	DF						
Phase	2		.0001	.0001	.0001		
Treatment	2		.2020	.0726	.3457		
	4		.0114	.0598	.1406		

[a-d] Means in a column within a phase with unlike superscript differ (P > 0.05)

[1] Log transformation was performed on data to normalize the distribution over the production cycle. Statistical differences are per transformed data. Reported means are the antilog of transformed lsmeans [2] ME content of diet was 3095, 3135 and 3267 kcal/kg in starter, grower and finisher respectively

[3] ECV(Effective Caloric Value)=7017.65491 + (1.3773*BWT)-(0.00009006*BWT_2)+((5.247565E- 8)*BWT_3)-(5200.87308*CFCR) + (1566.92696*CFCR*CFCR)-0.75909*BWT*CFCR)) [4] Lighting program defined as 12L:12D=12 hours continuous light followed by 12 hours continuous dark; 1L:1D represents 1 h lighting followed by 1 h dark repeated throughout the day; 23L:1D represents 23h of continuous light followed by 1 h dark each 24 h period

[5] Interval = 7-21, 21-35 and 35-50 days of age ; [6] Interval ECV consumption calculated as Interval ECV x Feed consumption; [7] Cumulative=1-21, 1-35 and 1-50 days of age ; [8] Cumulative ECV consumption calculated as as Cumulative ECV x Feed consumption

Table 5. Lighting program effects on effective caloric values relative to continuous light (23L:1D) and proportion of feed intake as maintenance in broilers of 21 -50 days of age reared under three lighting programs[1,2]

		Changes in Effective Caloric Values		Proportion of Calorie Intake as Maintenance	
Phase	Lighting program[3]	Interval Values[4]	Cumulative Values[5]	MEn System[6]	ECV System[7]
Starter					
(day 7– 21)	12L:12D	20.26	23.99	34 [b]	36 [b]
	1L:1D	28.23	26.76	33 [b]	34 [b]
	23L:1D	____	____	33 [b]	35 [b]
Grower					
(day 21–35)	12L:12D	76.21	122.28	31 [c]	33 [c]
	1L:1D	-54.41	-43.10	29 [c]	32 [c]
	23L:1D	_____	____	29 [c]	32 [c]
Finisher					
(day 35-50)	12L:12D	95.27	249.86	37 [a]	43 [a]
	1L:1D	-79.29	-75.08	37 [a]	42 [a]
	23L:1D	____	____	38 [a]	46 [a]
ANOVA	DF				
Phase	2	0.9824	0.3288	.0001	.0001
Treatment	2	0.0976	0.0001	.1465	.3034
Phase x TRT	4	0.5840	0.0030	.1034	.1682

[a-b] Means in a column with common superscript do not differ significantly (P > 0.05)

[1] ECV=7017.65491 + (1.3773*BWT) - (0.00009006*BWT_2) + ((5.247565E- 8)*BWT_3) - (5200.87308*CFCR) + (1566.92696*CFCR*CFCR) – 0.75909*BWT*CFCR)) [2] Analysis done by phase due to phase x treatment interaction

[3] Lighting program defined as 12L:12D=12 hours continuous light followed by 12 hours continuous dark; 1L:1D represents 1 h lighting followed by 1 h dark repeated throughout the day;23L:1D represents 23h of continuous light followed by 1 h dark each 24 h period

[4] Interval = 7-21, 21-35 and 35-50 days of age [5] Cumulative refers to (1-21), (1-35) and (1-50) days

[6] Metabolizable energy system calculated as (((initial weight + final weight) $^{.67}$) x .102 x test days)/ ME Consumption

[7] Effective caloric value system (((initial weight + final weight)$^{.67}$) x .102 x test days)/ Effective caloric value Consumption

Table 6. Lighting program effects on broiler body composition as live mass (g) and percentage on days 21, 35 and 50 following completion of the starter, grower and finisher phases[1]

Production		Water		Protein		Fat		Ash	
Phase	Lighting Program	(g)	(%)	(g)	(%)	(g)	(%)	(g)	(%)
Starter									
(Day 21)	12L:12D[2]	246 [b]	71.39 [c]	56.72 [b]	16.46 [b]	31.45 [b]	9.12 [a]	7.8 [b]	2.25 [b]
	1L:1D	267 [a]	71.90 [b]	61.76 [a]	16.63 [a]	34.59 [a]	9.31 [a]	8.6 [a]	2.30 [a]
	23L:1D	247 [b]	72.24 [a]	56.40 [b]	16.48 [b]	31.14 [b]	9.07 [a]	7.8 [b]	2.26 [b]
		_____Probability_____		_____Probability_____		_____Probability_____		_____Probability_____	
		.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001
Grower									
(Day 35)	12L:12D	794 [a]	67.38 [a]	204 [a]	17.32 [a]	144 [a]	12.23 [a]	30 [a]	2.56 [a]
	1L:1D	757 [b]	66.66 [b]	194 [c]	17.04 [b]	135 [c]	11.86 [a]	29 [b]	2.52 [a]
	23L:1D	771 [b]	66.70 [b]	198 [b]	17.14 [b]	139 [b]	12.02 [a]	29 [b]	2.52 [a]
		_____Probability_____		_____Probability_____		_____Probability_____		_____Probability_____	
		.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001
Finisher									
(Day50)	12L:12D	1578	61.89 [b]	446	17.49 [a]	408	15.94 [a]	66	2.58 [a]
	1L:1D	1513	62.55 [a]	420	17.60 [a]	382	15.74 [a]	63	2.59 [a]
	23L:1D	1587	62.10 [a]	450	17.59 [a]	413	16.08 [a]	66	2.59 [a]
		_____Probability_____		_____Probability_____		_____Probability_____		_____Probability_____	
		.0654	.0181	.0695	.0971	.0665	.2133	.0665	.2601

[a-b] Means in a column with common superscript do not differ (P > 0.05)

[1] Conducted due to interaction observed between phase and treatment

[2] Lighting program defined as 12L:12D=12 hours continuous light followed by 12 hours continuous dark; 1L:1D represents 1 h lighting followed by 1 h dark repeated throughout the day;23L:1D represents 23h of continuous light followed by 1 h dark each 24 h period

Table 7. Lighting program effects on fat to protein ratio of broilers on days 21, 35 and 50 following completion of the starter, grower and finisher phases

Production Phase	Lighting Program	Fat to protein ratio[1]
Starter		
(Day 7-21)	12L:12D[2]	0.55[a]
	1L:1D	0.56[a]
	23L:1D	0.55[a]
Grower		
(Day 21-35)	12L:12D	0.71[b]
	1L:1D	0.70[b]
	23L:1D	0.70[b]
Finisher		
(Day 35-50)	12L:12D	0.92[c]
	1L:1D	0.91[c]
	23L:1D	0.91[c]
ANOVA	DF	
Phase	2	0.0001
TRT	2	0.3924
Phase x TRT	4	0.5153

[a-d] Means in a column within a phase with common superscript do not differ significantly ($P > 0.05$)

[1] Fat to protein ratio =F / P

[2] Lighting program defined as 12L:12D=12 hours continuous light followed by 12 hours continuous dark; 1L:1D represents 1 h lighting followed by 1 h dark repeated throughout the day;23L:1D represents 23h of continuous light followed by 1 h dark each 24 h period

Table 8. Lighting program effects on calorie per gram of body weight of broilers on days 21, 35 and 50 follows completion of the starter, grower and finisher phases

Phase	Lighting Program[1]	Calorie content per Gram Live weight[2]
Starter		
(7-21d)	12L:12D[2]	1.78[a]
	1L:1D[3]	1.81 [a]
	23L:1D[4]	1.77 [a]
Grower		
(21-35d)	12L:12D	2.12 [b]
	1L:1D	2.07 [c]
	23L:1D	2.09 [c]
Finisher		
(35-50d)	12L:12D	2.49 [d]
	1L:1D	2.49 [d]
	23L:1D	2.49 [d]
ANOVA	DF	
Phase	2	0.0001
TRT	2	0.5689
Phase x TRT	4	0.1564

[a-d] Means in a column within a phase with common superscript do not differ significantly ($P > 0.05$)

[1] Lighting program defined as 12L:12D=12 hours continuous light followed by 12 hours continuous dark; 1L:1D represents 1 h lighting followed by 1 h dark repeated throughout the day;23L:1D represents 23h of continuous light followed by 1 h dark each 24 h period

[2] Calorie per gram of gain = (bird fat(g)x 9.31 + bird protein(g) x 5.65) / BW

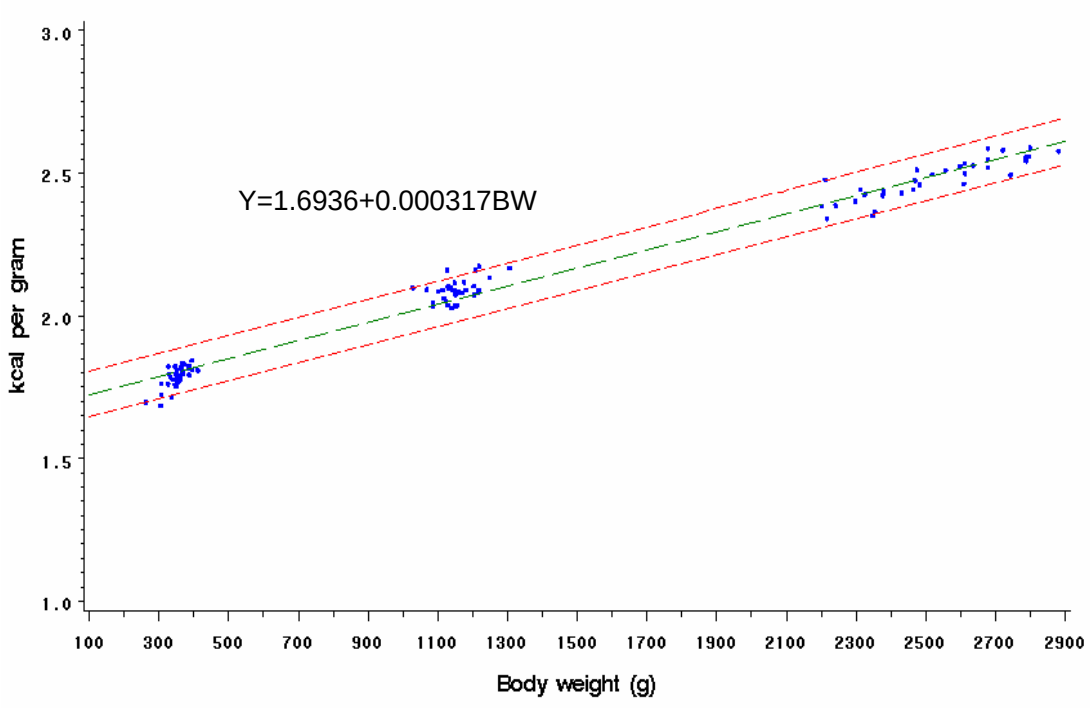

Figure 1. plot for lighting program effects on calorie content per gram of live weight for the starter, grower and finisher phases. Y=1.6936 + 0.000317BW (R^2=.9821; P < 0.0001)

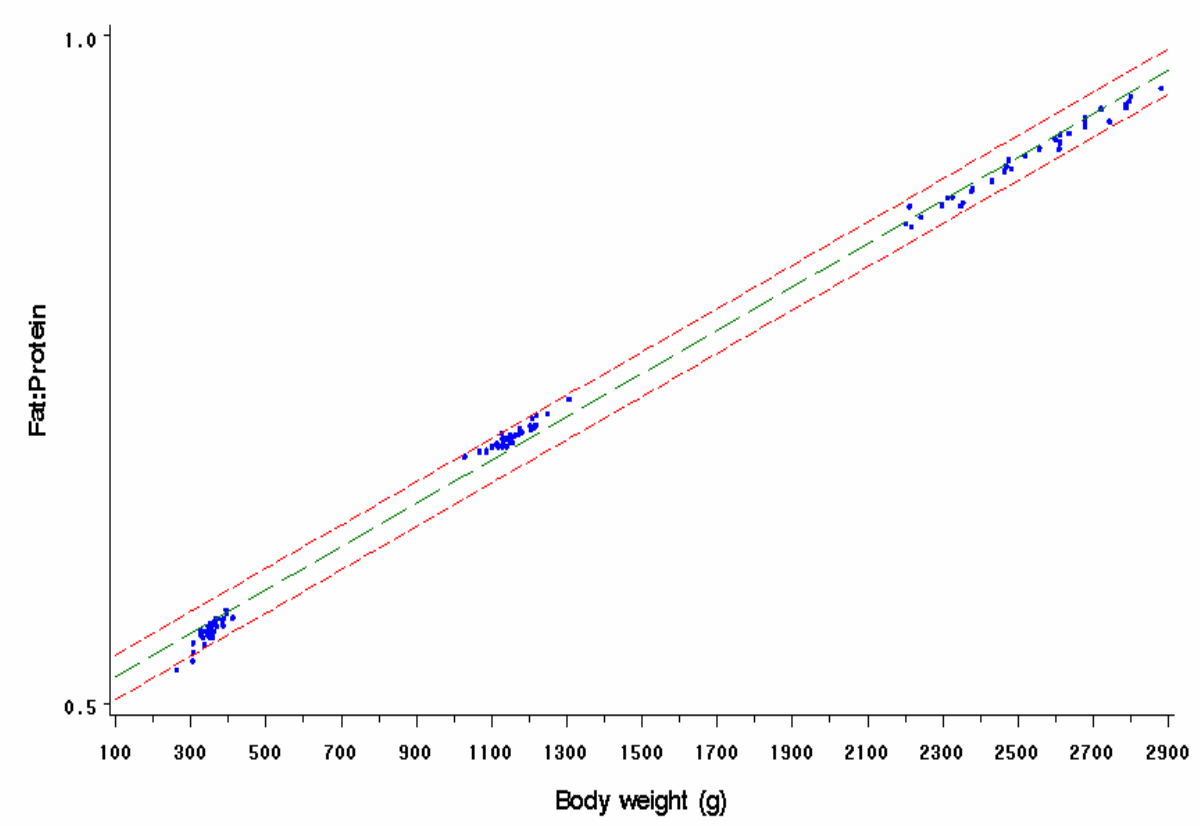

Figure 2. plot for lighting program effects on fat to protein ratio of broilers for the starter, grower and finisher phases. Y=0.50408 + 0.000161BW (R^2=.9969 ; P < 0.0001)

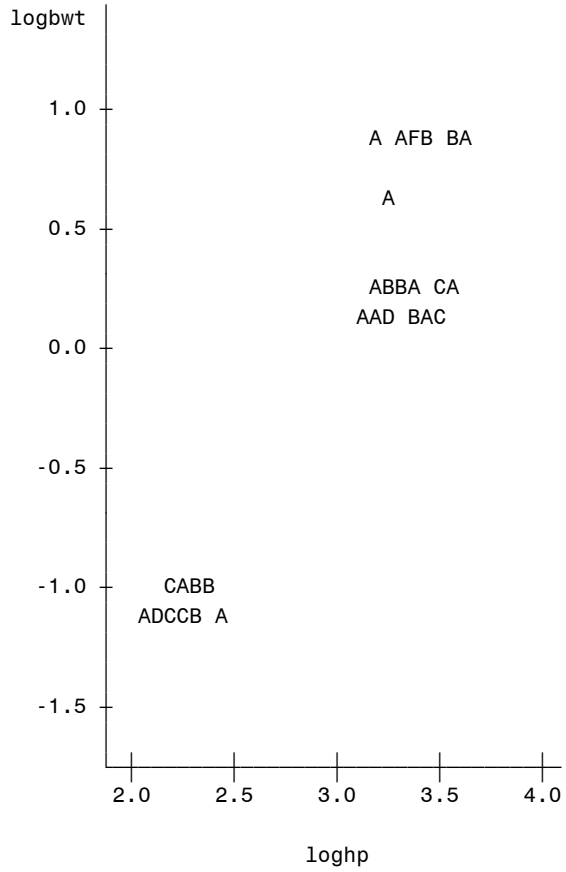

Figure 3. plot for log body weight by log heat production of broilers kept on the 12 hours of light and 12 hours of dark lighting program. Heat production at the end of 20, 34 and 49 days of age following fasting for 30 h is considered in computation.
Y=.3.0 + logBW x .67 R^2=.88 (P < 0.0001)

80

Table 9. Lighting program effects on metabolizable energy intake, effective caloric value, heat production, energy retention and efficiency of energy use during the starter, grower, and finisher phases for broilers reared under three lighting programs [1]

Phase	Lighting Program[2]	Variable: ME Intake (kcal)[3]	ECV Interval (kcal/kg)[4]	Heat Production (Kcal)[5]	RE (Kcal)[6]	Efficiency of ME use for RE[7]
Starter						
(7-21 days)	12L:12D	1660 [b]	2965 [bc]	353 [b]	1307 [b]	0.79 [a]
	1L:1D	1764 [a]	2974 [a]	381 [a]	1383 [a]	0.78 [a]
	23L:1D	1683 [b]	2946 [ab]	348 [ab]	1335 [b]	0.79 [a]
Grower						
(21-35 days)	12L:12D	5822 [b]	2916 [bcd]	2656 [c]	3166 [a]	0.54 [a]
	1L:1D	6225 [a]	2786 [ab]	2959 [b]	3266 [a]	0.52 [a]
	23L:1D	5708 [b]	2840 [bcd]	2899 [bc]	2809 [b]	0.49 [b]
Finisher						
(35-50 days)	12L:12D	8335 [a]	2827 [d]	4620[a]	3735 [a]	0.45 [a]
	1L:1D	7194 [c]	2675 [d]	4840 [a]	2354 [c]	0.32 [b]
	23L:1D	7336 [b]	2746 [d]	4763 [a]	2573 [b]	0.35 [b]
ANOVA	DF	Probability				
Phase	2	0.0001	0.0001	0.0001	0.0001	0.0001
Treatment	2	0.0001	0.0726	0.0026	0.0001	0.0001
Phase x TRT	4	0.0001	0.5298	0.8338	0.0001	0.0001

[a-d] Means in a column within a phase with common superscript do not differ (P > 0.05)

[1] Log transformation was performed on MEintake and NEgain data to normalize the distribution over the production cycle. Statistical differences are per transformed data. Reported means are the antilog of transformed lsmeans

[2] Lighting program defined as 12L:12D=12 hours continuous light followed by 12 hours continuous dark; 1L:1D represents 1 h lighting followed by 1 h dark repeated throughout the day;23L:1D represents 23h of continuous light followed by 1 h dark each 24 h period

[3] Metabolizable energy intake (ME I) = Feed consumption x ME (metabolizable energy)content of feed

[4] Efective caloric value for 7-21, 21-35, and 35-50 days respectively

[5] HP=(16.18 X O_2 consumed + 5.0$_2$ x CO_2 produced) x 4.184

[6] Retained energy (RE) = Metabolizable Energy Intake – Heat Production

[7] Efficiency ME use for RE = (Metabolizable Energy Intake – Heat Production) / Metabolizable Energy Intake

Table 10. Lighting program effects on oxygen consumption, carbon dioxide production and carbon utilization during the starter, grower, and finisher phases for broilers reared under three lighting programs

Production Phases	Lighting Program[1]	O2 Consumption (L)	CO2 Production (L)	Feed Carbon Consumption[2]	CO2 per Carbon Consumption[3]	CO2 per Feed per MBW[4]	Heat Production
Starter	12L:12D	271 [e]	301 [c]	415	1.38 [a]	0.12 [a]	3.7 [a]
(7-21 days)	1L:1D	294 [e]	323 [c]	449	1.39 [a]	0.12 [a]	3.9 [a]
	23L:1D	268 [e]	299 [c]	434	1.35 [a]	0.12 [a]	3.6 [a]
Grower	12L:12D	537 [d]	478 [b]	725	0.63 [b]	0.02 [b]	3.0 [c]
(21-35 days)	1L:1D	601 [c]	528 [b]	742	0.65 [b]	0.02 [b]	3.4 [b]
	23L:1D	587 [c]	498 [b]	742	0.68 [b]	0.02 [b]	3.3 [b]
Finisher	12L:12D	1032 [b]	1157 [a]	1170	0.53 [d]	0.01 [c]	2.9 [f]
(35-50 days)	1L:1D	1116 [a]	1197 [a]	1073	0.61 [c]	0.01 [c]	3.5 [d]
	23L:1D	1077 [a]	1177 [a]	1086	0.57 [d]	0.01 [c]	3.1 [e]
ANOVA	DF				Probability		
Phase	2	0.0001	0.0001	.0001	0.0001	0.0001	0.0001
TRT	2	0.0004	0.0462	.4963	0.3516	0.9461	0.0001
Phase x TRT	4	0.3417	0.9449	.0037	0.6004	0.6927	0.1471

[a-d] Means in a column within a phase with common superscript do not differ significantly ($P > 0.05$)

[1] Lighting program defined as 12L:12D=12 hours continuous light followed by 12 hours continuous dark; 1L:1D represents 1 h lighting followed by 1 h dark repeated throughout the day;23L:1D represents 23h f continuous light followed by 1 h dark each 24 h period

[2] Feed carbon (g) = (total CO_2 production/22.4) x .2727 x 12

[3] CO_2perCarbonCons = (((total CO_2 production/22.4) x .2727 x 12) /Carbon Consumption) x 100

[4] $CO_2$2perFeedConsperMBW=(TotCO_2Prod/FeedCon) / $BW^{.67}$ (kg)

CHAPTER IV

Substrate Effects on Broiler Energetic Efficiency

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Running head: Broiler Performance and Energetic Efficiency

Section: Metabolism and Nutrition

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ABSTRACT An experiment was conducted using 21d old male and female Cob 500 broilers to model metabolizable energy (ME) utilization using different substrates for maintenance, and tissue accretion partitioned into water, protein, fat and ash, and efficiency of ME above maintenance. Ten experimental diets were formulated by substituting, corn starch, corn oil and isolated soy protein for solka floc in a basal diet (2950 kcal/kg MEn and 20% CP). Each substrate substitution provided either 175 or 350 kcal MEn/kg as corn starch+isolated soybean meal, corn starch+corn-oil and corn oil+isolated soybean meal. Maintenance energy requirement was calculated as the intercept when ME intake was regressed on weight gain. No differences for bird maintenance energy need were detected between the two sexes. The maintenance energy requirement expressed per unit metabolic body size was 109.5 kcal/kg $BW^{0.67}$ /d. Increasing energy level of the basal diet from any substrate source improved ($P< 0.05$) body weight (BW) gain and feed efficiency of the birds. Maintenance energy requirement was not affected by sex, and was averaged to be 109.4 kcal/kg BW/d. Increasing energy level of the basal diet also showed an increase in both protein and fat gain of male broilers ($P < 0.05$) compared with females. In summary, energy supplementation to broiler diets improved performance. It also impacted body composition and increased fat to protein ration compared to the basal diet. Maintenance energy need was unaffected by sex, but efficiency of gain was greater for males compared with females. Variation in performance and body composition between sexes could be due to differences in activity. Thus, these results warrant further study to substantiate the effect of activity on performance and body composition of male and female broilers under a similar dietary regimen.
(*Key words: broiler, performance, maintenance energy, body composition)*

INTRODUCTION

Metabolizable energy (ME) has been the historical measure for evaluating dietary energy in poultry diet as it can be rapidly and precisely determined (Sibbald 1976; McNab and Blair, 1988). Consequently, ME intake (MEI) is the criteria by which poultry diets are formulated. However, additional information is needed to partition requirements into maintenance and accretion models to help establish better and more profitable feeding programs.

The conventional method to represent energy utilization has been the partition of MEI. According to Birkett & Lange (2001), the simplest approach to partition the MEI is in terms of its use by animal for production as retained energy (RE) and an amount associated with ME utilization for maintenance (MEm). $ME = MEm + (1/k_g)RE$. The energetic efficiency associated with maintenance (Km) versus accretion (Kg) have been documented (Kielanowski , 1965; Birkett & Lange, 2001). This simple model falls short, however, because it does not take into account the partial efficiencies of tissue accretion as fat and protein.

Research efforts have been directed towards quantifying the ME required for maintenance and the efficiency of ME utilization for broiler tissue accretion (Leclercq and Saadoun, 1982; Boekholt et al. 1994). The allocation of dietary energy in animals between maintenance, protein and lipid growth has often been investigated by a factorial approach. Since its development by Kielanowski (1965), the regression of MEI as a function of protein deposition (PD) and lipid deposition (LD) has been applied to investigate partitioning of ME between maintenance, protein, and lipid growth in various animals (Noblet et al., 1999). In order to model energy utilization more accurately for

varying fat to protein ratios in the RE, (Kielanowski, 1965) subdivided the RE into energy retained as fat (REF) and protein (REP), as ME = MEm + $(1/k_f)$REF + $(1/k_p)$REP. However, this approach has been criticized (Lehay, 2000; Neter et al., 1980; Noblet et al., 1999) as colinearity between protein and lipid accretion potentially biased the results when examined by regression techniques.

The classical definition of maintenance describes maintenance as the state in which there is neither gain nor loss of nutrient by the body (Blaxter, 1972). Therefore, the ME requirement for maintenance has been defined as the amount of energy required to balance anabolism and catabolism, giving an energy retention around zero. According to Chwalibog (1991), this definition is acceptable for adult but not for growing animals. The energy need for maintenance of the growing animal are defined as the amount of ME, which is completely excreted as heat at an energy balance equals to zero. However, under such conditions the animals are frequently utilizing lipid to support lean mass accretion, consequently the use of RE alone may be misleading.

The experimental evaluation of MEm in fast growing animals has indeed been questioned (Wenk, 1987; France et al., 1989). At low feeding levels, growing animals continue with a positive protein deposition, that is covered by mobilizing energy reserves from the fatty tissues making RE=0 while under a metabolically dynamic condition. The feeding condition at maintenance in the fast growing animal is, therefore, not a normal physiological status and has mainly a statistical meaning (Sakamura, 2004) as energetic equilibrium never occurs. In this case, Chwalibog (1985) defines the ME maintenance requirement as being the amount of ME to maintain a dynamic equilibrium of protein and fat turnover, to maintain body temperature and a normal level of locomotor activity.

Conversely, one could also state that the ration composition to elicit the maintenance state in a growing animal is unknown at this time.

Bird maintenance energy requirement have been estimated in feeding trials, by calorimetric measurements, and/or regression equations of energy balance components. Energy balance may be determined by direct calorimetry, indirect calorimetry, and carcass analysis. The indirect calorimetry method (Blaxter, 1989), measures the heat production (HP) by determining the O_2 consumed and CO_2 produced in respiration chambers, and has been applied in multiple studies (Grimberger, 1970; Spratt *et al*., 1990; Belay, 1991; Weirnuze, 1994; Beker, 1996). The comparative slaughter method estimates HP by the difference of MEI and RE (Wolynetz & Sibbald, 1987). Birds' need for MEm is subsequently determined by the linear relationship between RE and MEI, where the intercept on the x axis provides MEm, as the MEI consumption associated with zero RE (Farrel, 1974). Another method uses the logarithmic relationship between heat production and MEI provides the maintenance net energy requirement (NEm), and fasting heat production (Lofgreen & Garret, 1968). Several factors can affect the energy metabolism, such as animal age, body weight, body composition, size of organs, and growing or production stages (Blaxter, 1989; Beker , 1996, Table 1; and Sakomura, 2004 Table 3-). Darmani et al. (2003) analyzed data from six studies with male broilers aged 7-70 days and fed diets covering a wide range of energy and protein. The ME requirement for maintenance was determined to be in the range of 104 – 137 kcal/kg of body weight/day depending on the model (linear, monomolecular, rectangular hyperbola, Gompertz and logistic. The values determined for average net energy requirement for body weight gain varied from 1.9 – 2.7 kcal/g of body weight.

There is a marked difference in efficiency of utilization of the ME from the three substrates as protein, fat and carbohydrate. Metabolizable energy from carbohydrates has a net availability of about 75%, protein about 60% and fat about 90% (DeGroote et al., 1974). Utilization efficiency of the ME of carbohydrates, fats and proteins for lipogenesis in cockerels is 75, 84, and 61% respectively. The net energy values of diets high in fat may, therefore, be underestimated compared to diets high in carbohydrates unless some correction is applied to the ME values to take into consideration the differences in energy utilization. These aspects are for energy catabolism consideration, an additional concern would be that direct deposition of substrate as amino acids, lipid and glucose into animal tissue would have much higher efficiency value.

The study reported herein was designed to determine maintenance energy need of broilers during the grower phase as influenced by diet composition and further to estimate efficiency of gain for energy consumed above maintenance which is derived from carbohydrate, protein and fat sources in the diet.

MATERIALS AND METHODS

General:

Day old chicks were obtained from a commercial hatchery, raised in floor pens with wood shaving litter and fed standard ration described by Skinner Noble and Teeter (2004) until they reached 3 weeks of age. Procedures of live animal use were consistent with guidelines of the Laboratory Animal Resources Committee of Oklahoma State University and have been described elsewhere (Skinner-Noble and Teeter, 2004). At experiment initiation, male and female chicks 90 from each sex were placed in individual

bird wire cages (46 x 60 cm) with paper and shaving placed on cage floors. Experimental diets were formed by the addition of 2 levels of substrate (corn starch, corn oil and isolated soy protein) to provide 175 and 350 kcal fortification to a nutritionally complete basal diet (Table 3). The ten experimental diets were formed by substituting substrates for Solka-floc in the basal diet that provided 2950 kcal/kg MEn and 20% CP (Tables 4). All other nutrients except energy met or exceeded NRC (1994) recommendations. Following eight hours of adaptation to the wire cages birds were fasted, initial live body composition determined and the 8 day feeding period initiated. The total daily feed offerings were divided into three equal parts and offered at 6 h, 14 h, and 22 h. Each diet was fed at three feeding levels of 40, 75 and 105% of initial body weight. The 105% of ad libitum consumption level was used to assure that feed intake approached ad libitum consumption level for the highest feeding group as estimated from modeled live weight and feed consumption relationships. The body weight-feed consumption model was attained by regressing feed intake on body weight as following the formula shown below (Figure 1):

$$\textbf{Daily Predicted FI (g/b/d)} = (-1.0638*10^{-12}*BWT^4) + (1.1058*10^{-8}*BWT^3) + (-0.00005493*BWT^2) + (0.15974*BWT)$$

Where: BWT=Body weight (g)

BWT^2=BWT x BWT

BWT^3=BWT x BWT x BWT

BWT^4=BWT x BWT x BWT x BWT

During the course of the study birds were provided with strict quanta of feed for the three times daily feedings. Feed refusals and orts were quantified and subtracted from

the amount provided such that precise ration and hence supplemental substrate might be calculated. To minimize energy expenditure due to activity, and yet allow the birds' sufficient time to finish their feed allocation and drink water, light was turned on for nine hours during the feeding period (6-9 h, 14-17 h, and 22-1 h). Body weight accretion during the feeding period was computed as the difference between initial and final body weights.

Whole body composition was determined using a Multiple Detector, fan-beam Dual-energy X-Ray Absorptiometry (DEXA) bone densitometer[1]. Birds were fasted (8 h), anesthetized (Skinner-Noble et al., 2005), and scanned 6 consecutive times in the prone position. Equations developed by Mckinney and Teeter (2004) were used to adjust DEXA measurements to match what would otherwise have been obtained by proximate analysis (AOAC, 1990). As a check of DXA results, the summation of the adjusted bird protein, water, lipid, and ash were compared with the gravimetric weight. Body weight calculated from DXA measurements that were ± 5% of the respective gravimetric weight were excluded. The accepted scans for each bird were combined for analysis. Birds were scanned for compositional analysis at the start and completion of the experiment. Scanning was done on anesthetized live birds at the beginning and euthanized birds at the end of the study. Previous works (McKinney, 2004) in our laboratory showed this to be an effective method to relate DEXA values to proximate analysis values. This methodology enables analysis of whole body composition without bird sacrifice. Water, protein, lipid and ash were accordingly estimated as:

Bird Water = (5.79504) + (0.76994 x Fatg_1) + (-0.00003797 x Fatg_2) + (0.68501 x Lean_1) + (-0.00001373 x Lean_2) + (-0.00015077 x LeanFatg_1) + (2.43437E-11 x LeanFatg_2)

[1] QDR 4500 Elite X-Ray Bone Densitometer. Hologic, Inc. 35 Crosby Dr. Bedford, MA 01730 USA

Bird Protein = (-6.13349) + (0.1119 x Fatg_1) + (0.00003567 x Fatg_2) + (0.18308 x Lean_1) + (-0.00000370 x Lean_2) + (0.00004728 x LeanFatg_1) + (-1.252E-11 x LeanFatg_2)

Bird Fat = (-5.6813) + (0.03129 x Fatg_1) + (0.00006536 x Fatg_2) + (0.10041 x Lean_1) + (0.00002336 x Lean_2) + (0.000096 x LeanFatg_1) + (-1.2042E-11 x LeanFatg_2)

Bird Ash = (-1.6675) + (0.01579 x BMC_1) + (0.02658 x Lean_1) + (0.02434 x Fatg_1) + (-0.00000395 x LeanBMC_1) + (-0.00000254 x FatgBMC_1) + (0.00000144 x LeanFatg_1)

Where: Fatg_1 is fat (g)
Fatg_2 is fat (g) squared
Lean_1 is lean mass (g)
Lean_2 is lean mass (g) squared
LeanFatg_1 is the product of lean times fat (g)
LeanFatg_2 is the product of lean times fat (g) squared
BMC_1 is bone mass content (g)
LeanBMC_1 product of lean times bone mass content (g)
FatgBMC_1 product of fat times bone mass content (g)

Biological protein and lipid values were estimated as:

Biological protein value = protein gain during feeding interval / digestible protein consumption

Biological lipid value = lipid gain during feeding interval / digestible lipid consumption

Statistical Analysis

Statistical analyses were performed using SAS software (SAS, 2002). Regression analysis (REG procedure) was used to quantify the change in daily MEI per initial metabolic body weight as a function of change in body weight as well as RE. The intercept is considered as the maintenance requirement. Means and analysis of variance for weight gain, feed conversion (feed: gain), retained energy, protein and fat gain and fat to protein ratio were calculated using the general linear models procedure of SAS. When the F-test was significant, treatment means were separated using least significant difference.

Results

The experiment was successfully conducted. Treatment diets used in this study comprised the basal ration fortified with energy supplements from starch, fat, isolated soy protein and their combinations. Animal variability made strict separation of dietary treatments, energy level uncertain (Tables 5, 6, 7, 8, 10, 11 and 12). Consequently, the following analysis examines energy supplementation averaged over substrate source as basal, basal + 175, and basal + 350 kcal/Kg. Results thereby focus upon the effect of energy supplementation, regardless of source, on performance of male and female broilers fed to 40, 75, and 105 % of ad libitum consumption per initial body weight. Feed and MEI, body weight gain and feed efficiency are depicted in Tables 13. Live body composition data is presented in Table14. Maintenance data and the efficiency of ME use for gain (kg) are presented in Table 16 and 17. Maintenance energy need, averaged over sex is presented in Table 15.

40% feeding level:

Neither the sex effect nor its interaction ($P > 0.05$) with supplementary energy level was present for feed intake (Table 13). Since these birds were limit fed, feed intake was not expected to differ between treatments. Averaged over sex, as the supplementary energy level was increased, the ME intake rose incrementally ($P < 0.001$) from 120 for the basal to 126 and 134 kcal for the medium and high energy levels, respectively. Increasing supplementary energy level to 350 kcal/kg increased weight gain and gain to feed ratio ($P < 0.05$) compared to the basal diet for both sexes (Table 13). It should be noted that basal diet feeding at 40% of ad libitum consumption per initial body weight

was in slight excess of the projected maintenance energy need (32% of appetite consumption level (Cobb, 2004) and that most birds gained weight (g). Similar results have been reported (Lema, 1994; Beker, 1996). Viewed over sex, energy fortification at the 0, 175, and 350 kcal/kg resulted in body weight gain per initial metabolic body weight and gain/feed (FDEFF) averaging 7.4, 12.0, and 13.8 g/IMBWT and 0.16, 0.26, and 0.30, respectively (Table 13). As is depicted in Table 13, sex and sex by energy interaction did not have impact on live body composition. Averaged over sex, birds at 40% level of feeding gained protein, ash and water but, lost fat.

75% feeding level:

Feed intake was not impacted by sex, supplemental energy level or their interaction at the 75% feeding level. Metabolizable energy intake (MEI), body weight gain (BWgain), and FDEFF increased with supplementary energy ($P < 0.05$). Averaged over sex, as the supplementary energy level was increased to 175 and 350kcal/kg, MEI, BWgain and FDEFF increased ($P < 0.05$) by 236 and 249 kcal/d, 48 and 47g/d, and .64 and .63 points for the medium and high energy levels, respectively (Table 13). As is depicted in Table 14, no sex by energy interaction was noted for live composition. Therefore, main effects were considered. At near ad libitum consumption, male birds gained more protein (13.7 vs 12.3 g/d), fat (9.6 vs 8.5 g/d) and energy (180 vs 70 kcal/d) and with higher fat to protein ratio than females (Table 14 and 16).

Near ad-libitum (105%) feeding level:

At the near ad libitum feeding level, no significant interaction was noted between sex and supplementary energy level ($P > 0.05$) for the performance variables considered. As expected, feed intake was not impacted by sex or supplemental energy level ($P > 0.05$) while MEI rose with every level ($P < 0.05$). Viewed over sex, daily MEI per initial body weight (MEI/IBW/d), weight gain per initial metabolic body weight (BWgain/IMBW/d) and feed efficiency (FDEFF) were increased ($P < 0.05$) from 396 to 418 kcal/d, 83.4 to 87.3g/d and .70 to .73 respectively, when energy fortification increased from 175 to 350 kcal/kg (Table 13). Both sex and supplemental energy level impacted live body composition ($P < 0.05$). As is shown in Table 14, males gained more than females in all the composition parameters considered. Protein fat, ash, and water gain as well as fat to protein ratio increased linearly as the supplemental energy level increased ($P < 0.001$) to 350 kcal/kg.

Maintenance

As presented in the above sections daily weight gain per initial metabolic body weight increased linearly with daily energy consumption. Results are graphically displayed in Figure 2. Regressing daily MEI consumed on daily live weight gain enables estimation of energy need for body weight homeostasis (intercept) and energy need for a unit of body weight gain (slope) as is shown in Figure 3.

Similarly regressing MEI on RE enables estimated need for energy homeostasis. The maintenance requirement under both considerations are shown in Table 15. Maintenance energy need was not impacted by sex and supplemental energy level but differed

markedly for the two regression techniques. Averaged over sex and supplementary energy level, energy need for body weight homeostasis was estimated to be 109.5kcal/$kg^{.67}$/d (Figure 2). Regressing MEI on energy gain instead of live weight gain, however, yielded 139.4 kcal/$IBW^{0.67}$/d (Figure 3).

Discussion

In agreement with previous studies such as those of Pesti and Fletcher, (1983), Hurwitz et al., (1983, 1978), and Plavnik et al., (2002), the present study demonstrated that energy supplementation in any form of substrate improved performance. Live weight gain and feed efficiency were improved by increasing energy density level by 175 and 350 kcal/kg of diet suggesting that increasing caloric density of diet above 2950 kcal/ kg (Basal), improved performance of modern strain broiler. The positive response of feed efficiency to energy was observed along the entire range of feeding levels, although the responses to energy appeared to diminish as energy increased (Table 13).

Daily weight gain per initial metabolic body weight increased markedly with daily energy consumption as shown in Figure 2. This response can be used to estimate the birds' maintenance energy need for body weight homeostasis.

Averaging over sex and supplementary energy level, as maintenance energy need was estimated to be 109.5 kcal/$kg^{.67}$/d when MEI is regressed on body weight gain. This maintenance requirement value is similar to the classical value of 110 kcal/$kg^{.75}$/d (Summer and Leeson, 1989) and that of Darmani et al., (2003). Darmani obtained a maintenance energy value of 104 – 137 kcal/kg body weight /d.

The value determined for average net energy requirement for body weight gain, 3.18 kcal/g of body weight was higher than the values (1.9 – 2.7 kcal/g) reported by Darmani et al., (2003). Regressing MEI on energy gain instead of live weight gain yielded 139.4 kcal/$IBW^{0.67}$/d for energy homeostasis. At low feeding levels, the birds continued to grow (positive protein deposition) even though they were in negative energy balance (Figure 4) by mobilizing energy reserves from the fatty tissues for lean tissue accretion. Maintenance energy need of older birds was reviewed by Beker, (1996) appear to be higher than the modern strains (Sakomura, 2004). At a low maintenance level feeding, although the birds were in negative energy balance, they continued to grow with a positive protein deposition (Figure 4). These could be possible as a result of the fast growing birds' ability to cover their energy need by mobilizing energy reserves from the fatty tissue (Sakamura, 2004).

Dietary energy use by males was improved ($P < 0.05$) over females for kg despite similarity of maintenance energy need (Table 17). Yet the male and female birds consumed similar amounts of dietary energy and nutrients. Either male birds handle energy differently than females or they expressed less energy for activity. Evidence collected in our laboratory does indeed suggest that male birds have high resting frequency than their lighter but similar age female counterparts. Evidence also exists that diet metabolism may also be different. Estimated biological protein and lipid value differed with males having higher BPV and BLV than females, suggesting that direct deposition of substrates would be associated with improved energetic efficiency. The correlation between kg and BPV is 0.67 and kg and BLV is 0.87 (Table 9).

Biochemical Summation

Direct Deposition

Protein gained (g) = 110.7
Energy of protein gained (kcal) = 5.65kcal/g*110.7g = 625.5 kcal
Moles per kg of broiler protein = 8.4 moles of AA bonds
ATP per mole of broiler protein = 8
kcal per mole of broiler protein = 7.3

i) Efficiency of protein synthesis calculated via ATP

E Synthesis = mole/kg protein * kg protein * ATP/mole * kcal/ATP
= 8.4 * .1107 * 8 * 7.3
= 54.3 kcal
Total E Prot s+g = 625.5 kcal + 54.3 kcal = 679.8 kcal
Efficiency via ATP = E Prot gain / (E Prot gained+ E Synthesis)
= 625.5 / 679.8
= 92.01 %

ii) Efficiency of broiler protein synthesis via Glucose

ATP required = 54.3 / 7.43 = 7.4 ATP

Moles of glucose required=7.43 / 36 = 0.206 moles

E glucose required = 0.206 * 673 = 138.6 kcal

Total EProts+g = 625.5 kcal + 138.6 kcal = 764.1 kcal
Efficiency via Glucose ATP = E Prot gained / (E Prot gained + E Synth)
= 625.5 / 764.1
= 82 %

Direct Deposition of Lipid

Energy yield of tripalmitin = (3 x 2529.3) = 7588 kcal (Blaxter, 1989)

Energy yield of glycerol = 344 kcal (Blaxter, 1989)

Efficiency of direct deposition = 7588 / (7588 +344)
= 0.9566
= 96%

Fat synthesis from glucose

Fat gained (g) = 66.2
Energy of fat gained (kcal) = 59.3*66.2= 615.66

Efficiency of fat synthesis (Trioleaic acid via glucose)

Needed 14 moles of glucose at 678 kcal each = 9422 kcal
70 ATP at 7.3 kcal each = 511 kcal
Total 9933 kcal

Synthesized Trioleal glycerol = (mwt x 39.8) / 4.184 (kcal)
= 8428 kcal

Efficiency = E for synthesis of fat / Total Energy
= 8428 kcal / 9933 kcal
= 84.8%

Biochemical examination of tissue accretion indicates that direct deposition is much improved over synthesis for substrates. The elevated BPV and BLV of male birds shows that part of the advantage of males is due to their ability to directly deposit dietary substrates into tissue.

Summary and Conclusion

In summary, energy supplementation to broiler diets improved performance. It also impacted body composition and increased fat to protein ration compared to the basal diet. Maintenance energy need was unaffected by sex, but efficiency of gain was greater for males compared with females. Variation in performance and body composition between sexes could be due to differences in activity. Thus, these results warrant further study to substantiate the effect of activity on performance and body composition of male and female broilers under a similar dietary regimen.

Table 1. Energy need for body weight homeostasis, protein and fat accretion

Species	BWT (kg)	Maintenance need Kcal/kg$^{.75}$/d	Protein (KJ/KJ)	Fat (KJ/KJ)	Source
Chicken	0.175	162.9			Balnave, 1974
WL pullets	0.445	138.2			
Broiler	0.25 – 0.70	129.06			DeGroote, 1968
Male	1.9 – 2.8	134.56			Shannon & Brown, 1970
Rats (Lean)	0.20 – 0.35		2.25	1.36	Pullar and Webster, 1977
Pigs	0.20 – 0.35		1.54	1.15	Close and Stainer, 1984
Broilers	0.40	168.99			Pinchasov, 1970
	1.06	156.14			
Pullets	2.01	147.72			
Broiler	0.68	199.09			Jones, 1994

Source: Beker, 1996.

Table 2. Maintenance metabolizable energy requirement (MEm), Maintenance net energy requirement (NEm), efficiency of energy utilization above maintenance (kg), and for maintenance (km) according to ambient temperatures, and poultry type[1]

Poultry Type	Temperature (^{0}C)	Requirements (kcal/kg$^{0.75}$/day MEm	NEm	Efficiency Kg	Km
Laying-type pullets (cage)	12	142	---	---	---
Laying hens (cage)	12	138	100	0.66	0.72
Broiler breeder pullet (ground)	15	158	119	0.69	0.75
Broiler (ground)	13	158	119	0.63	0.76
Broiler breeder hen (ground)	13	13	131	111	---
Broiler breeder hen (cage)	78	---	0.61	---	0.70
Laying-type pullets (cage)	24	94	0.59	0.67	---
Laying hens (cage)	22	112	80	0.62	0.71
Broiler breeder pullet (ground)	22	144	109	0.69	0.76
Broiler breeder hen (ground)	21	21	113	91	---
Broiler breeder hen (cage)	65	---	0.60	---	0.71
Broiler (ground)	23	112	90	0.59	0.80
Laying typed pullets (cage)	30	109	---	---	---
Laying hens (cage)	31	93	69	0.69	0.74
Broiler breeder pullet (ground)	30	128	92	0.62	0.72
Broiler breeder hen (ground)	30	30	111	88	---
Broiler breeder hen (cage)	59	---	0.57	---	0.67
Broiler (ground)	32	127	96	066	0.76

1 Data extracted from Sakomura (2004)

Table 3.Composition of the basal diet used in the grower phase study

Ingredient name	**%**
Corn	57.98
Soybean meal	18.36
Cellulose	8.86
Corn gluten meal	4.50
Pro-pak1	3.50
Corn oil	3.11
Di-calcium phosphate	1.05
Limestone	0.81
Sodium bicarbonate	0.44
Vitamin premix[1]	0.35
Lysine HCl	0.31
Salt	0.20
L-arginine (Mono-HCl)	0.18
DL-methionine (99%)	0.13
Trace mineral premix [2]	0.08
Threonine (98.5%)	0.07
Bio-cox 60	0.06
Selenium 600 premix	0.02
Calculated Analysis	
ME, kcal/kg	2950
Crude protein	20
Digestible Crude Protein[5]	5.9
Crude Fat	
Digestible Crude Fat[6]	
Crude fiber	2.1
Starch	
Calcium	0.8
NonPhytate Phosphorus	0.4
Sodium	0.22
Potassium	0.57
Chloride	0.25
Digestible amino acids[3]	
Arginine	1.21
Histidine	0.43
Isoleucine	0.71
Leucine	1.86
Lysine[4]	1.03
Methionine	0.49
Cystine	0.33
Phenylalanine	0.89
Threonine	0.68
Tryptophan	0.13
Valine	0.82

[1]Supplied per kg diet: vitamin A, 14,109 IU (retinyl acetate); cholicalciferol, 5,291 IU; vitamin E, 47.6 IU (dl-α-tocopheryl acetate);vitamin B_{12}, .014 mg; riboflavin, 8.82 mg; niacin 26.5 mg; d-pantothenic acid, 28.2 mg; choline, 705.5mg; menadione, 1.16 mg; folic acid, 1.176 mg; pyridoxine, 3.52 mg; thiamin, 3.52 mg; d-biotin, 0.176 mg. [2]Supplied per kilogram of diet: Ca, 160 mg; Zn, 100 mg; Mn, 120 mg; Fe, 75 mg; Cu, 10 mg; I, 2.5 mg.

[3]Based on digestibility coefficients reported by Ajinomoto Heartland, Incorporated (2001).[4]Includes amino acids from intact protein and crystalline sources, which were assumed 100% digestible.

Table 4. Percentage composition of experimental diets fed to three week old mixed sex broilers during the grower and finisher period

	Experimental Diets									
	Basal[1]	Starch		Fat		Protein		Substrate Mixture		
Ingredient	A	B	C	D	E	F	G	H	I	J
Basal[1]	91.14	91.14	91.14	91.14	91.14	91.14	91.14	91.14	91.14	91.14
Cellulose[2]	8.86	4.43	-----	6.86	4.86	4.74	0.62	0.31	2.43	2.74
Corn Starch[3]	-----	4.43	8.86	-----	-----	-----	-----	4.43	4.43	-----
Corn Oil[4]	-----	-----	-----	2.00	4.00	-----	-----	-----	2.00	2.00
Isolated SBM[5]	-----	-----	-----	-----	-----	4.12	8.24	4.12	-----	4.12
	Energy Provided									
Basal	2950	2950	2950	2950	2950	2950	2950	2950	2950	2950
Substrate		175		175		175				
Low Substrate			350		350		350	350	350	350
High Total Diet (kcal/kg)	2950	3125	3300	3125	3300	3125	3300	3300	3300	3300

[1] See Table 2 for composition of basal ration
[2] Sulka flok
[3] MEn value=3950 kcal/kg (Wiernusz, 1994)
[4] MEn value=8750 kcal/kg (Wiernusz, 1994)
[5] MEn value=4246 kcal/kg (Wiernusz, 1994)

Table 5. Effect of sex and substrate on performance of broilers limit fed (40%) from day 21 through 29

FL (%)	Sex	Substrate	FI (g/d)	FI per IMBW (g/BW$^{.67}$/d)	MEI (Kcal/kg/d)	MEI per IBW (Kcal/kg/d)	BW gain (g/d)	BWgain per IMBW (g/BW$^{.67}$/d)	FDEFF
40	F	Basal	40.5	45.50	120.13	142.50	1.88	1.50	0.03
	F	Carb	40.5	45.63	130.13	155.13	10.98	12.38	0.27
	F	CarbFat	40.5	45.50	133.75	159.38	12.50	13.88	0.30
	F	CarbProt	40.5	45.50	133.38	159.63	12.50	14.38	0.32
	F	Fat	40.5	45.63	130.00	155.25	11.25	12.75	0.28
	F	FatProt	40.6	45.75	133.88	159.88	10.00	11.25	0.25
	F	Prot	40.5	45.50	130.13	155.00	13.75	15.00	0.33
	M	Basal	40.5	45.63	119.75	142.63	10.00	11.00	0.24
	M	Carb	40.5	45.50	130.13	142.75	10.00	11.00	0.26
	M	CarbFat	40.5	45.50	133.63	159.38	10.00	11.00	0.24
	M	CarbProt	40.5	45.63	133.75	159.50	12.50	11.00	0.31
	M	Fat	40.5	45.63	130.13	155.25	10.00	11.00	0.25
	M	FatProt	40.5	45.50	133.50	159.75	13.75	11.00	0.33
	M	Prot	40.5	45.63	130.13	155.38	13.75	11.00	0.35
		ANOVA				P			
		Sex	NS	NS	NS	NS	NS	NS	NS
		Substrate	NS	NS	**	**	**	**	**
		Sex x Substrate	NS	NS	NS	NS	NS	NS	NS

* = P < 0.05; ** = P < 0.001 ; NS = P > 0.05; FL = Feed Level (% of ad lib); Basal=corn soy ; Carb=supplemented with corn starch; CarbFat=corn starch- corn oil supplemented diet; CarbProt=corn starch- isolated soy combination diet; Fat=corn oil supplemented diet; FatProt=corn oil-isolated soy combination diet; Prot=isolated soy supplemented diet; FI = Feed Intake;
FI per IMBW = FI / initial metabolic body weight; MEI = Metabolizable energy Intake; MEI per IBW = MEI / Initial Body Weight ;BW gain = Body Weight gain**;** BWgain per IMBW =BWgain / Initial Metabolic BW; FDEFF=Feed Efficiency

Table 6 Effect of sex and substrate on performance of broilers limit fed (75%) from day 21 through 29

FL (%)	Sex	Substrate	FI (g/d)	FI per IMBW ($g/BW^{.67}/d$)	MEI (Kcal/kg/d)	MEI per IBW (Kcal/kg/d)	BW gain (g/d)	BWgain per IMBW ($g/BW^{.67}/d$)	FDEFF
75	F	Basal	75.50	85.25	222.75	267.88	34.50	38.63	.45
	F	Carb	75.50	85.38	242.88	291.63	44.63	50.63	.59
	F	CarbFat	75.63	85.50	249.63	299.63	43.75	49.50	.58
	F	CarbProt	75.63	85.50	249.75	299.75	49.25	55.63	.65
	F	Fat	75.50	85.25	240.63	290.38	42.63	48.38	.57
	F	FatProt	75.63	85.50	249.50	299.75	46.38	52.38	.61
	F	Prot	75.50	85.25	242.63	291.50	51.38	58.00	.68
	M	Basal	75.63	85.50	222.88	268.13	35.50	40.25	.47
	M	Carb	75.50	85.38	242.75	291.63	49.25	55.75	.65
	M	CarbFat	75.63	85.50	249.50	299.63	47.63	53.75	.63
	M	CarbProt	75.38	85.13	249.13	299.63	47.38	53.50	.63
	M	Fat	75.50	85.38	244.00	293.25	44.50	50.38	.59
	M	FatProt	75.50	85.38	249.13	299.63	56.50	64.13	.75
	M	Prot	75.50	85.38	242.50	291.63	50.25	56.88	.67
		ANOVA				P			
		Sex	NS	NS	NS	NS	NS	NS	NS
		Substrate	NS	NS	**	**	**	**	**
		Sex x Substrate	NS	NS	NS	NS	NS	NS	NS

* = P < 0.05; ** = P < 0.001 ; NS = P > 0.05; FL = Feed Level (% of ad lib); Basal=corn soy ; Carb=supplemented with corn starch; CarbFat=corn starch- corn oil supplemented diet; CarbProt=corn starch- isolated soy combination diet; Fat=corn oil supplemented diet; FatProt=corn oil-isolated soy combination diet; Prot=isolated soy supplemented diet; FI = Feed Intake;
FI per IMBW = FI / initial metabolic body weight; MEI = Metabolizable energy Intake; MEI per IBW = MEI / Initial Body Weight ;BW gain = Body Weight gain**;** BWgain per IMBW =BWgain / Initial Metabolic BW; FDEFF=Feed Efficiency

Table 7. Effect of sex and substrate on performance of broilers fed near ad libitum from day 21 through 29

FL (%)	Sex	Substrate	FI (g/d)	FI per IMBW ($g/BW^{.67}/d$)	MEI (Kcal/kgd/)	MEI per IBW (Kcal/kg/d)	BW gain (g/d)	BWgain per IMBW ($g/BW^{.67}/d$)	FDEFF
105	F	Basal	106.75	119.75	314.88	373.88	58.00	65.00	.54
	F	Carb	106.63	119.63	340.88	404.63	73.75	82.88	.69
	F	CarbFat	106.63	119.63	351.88	418.00	70.25	79.00	.66
	F	CarbProt	106.63	119.75	352.00	418.38	83.25	93.63	.78
	F	Fat	106.63	119.63	342.75	407.38	69.13	77.63	.65
	F	FatProt	106.63	119.75	351.88	418.25	78.63	88.25	.74
	F	Prot	106.63	119.63	342.63	407.25	76.50	86.00	.72
	M	Basal	106.63	119.63	315.00	373.75	65.63	73.50	.61
	M	Carb	106.63	119.63	340.88	405.00	81.25	91.13	.76
	M	CarbFat	106.75	119.75	352.13	418.25	75.38	84.63	.71
	M	CarbProt	106.63	119.63	352.00	418.00	79.38	89.13	.74
	M	Fat	106.63	119.63	342.38	407.25	75.13	84.38	.71
	M	FatProt	106.63	119.75	351.88	418.38	83.25	93.50	.78
	M	Prot	106.63	119.75	342.63	407.00	79.75	89.50	.75
		ANOVA				P			
		Sex	NS	NS	NS	NS	**	**	**
		Substrate	NS	NS	**	**	**	**	**
		Sex x Substrate	NS	NS	NS	NS	NS	NS	NS

P < 0.05; ** = P < 0.001 ; NS = P > 0.05; FL = Feed Level (% of ad lib); Basal=corn soy ; Carb=supplemented with corn starch; CarbFat=corn starch- corn oil supplemented diet; CarbProt=corn starch- isolated soy combination diet; Fat=corn oil supplemented diet; FatProt=corn oil-isolated soy combination diet; Prot=isolated soy supplemented diet; FI = Feed Intake; FI per IMBW = FI / initial metabolic body weight; MEI = Metabolizable energy Intake; MEI per IBW = MEI / Initial Body Weight; BW gain = Body Weight gain**;** BWgain per IMBW =BWgain / Initial Metabolic BW; FDEFF=Feed Efficiency

Table 8. Effect of substrate on performance of broilers from day 21 through 29 averaged over sex at different level of feeding

FL	Substrate	FI (g/d)	MEI (kcal/d)	BW gain (g/d)	FDEFF
40	Basal	40.5	119.88 [c]	6.63 [c]	0.16 [c]
	Carb	40.5	130.13 [b]	10.75 [b]	0.26 [b]
	CarbFat	40.5	133.63 [a]	11.13 [ab]	0.27 [b]
	CarbProt	40.5	133.63 [a]	12.63 [ab]	0.31 [ab]
	Fat	40.5	130.13 [b]	10.50 [b]	0.26 [b]
	FatProt	40.5	133.63 [a]	11.63 [ab]	0.29 [ab]
	Prot	40.5	130.13 [b]	13.75 [a]	0.34 [a]
	ANOVA				
	Subst	NS	**	**	**
75	Basal	75.63	222.88 [c]	35.00 [d]	0.46 [c]
	Carb	75.50	242.75 [b]	47.00 [b]	0.62 [b]
	CarbFat	75.63	249.63 [a]	45.75 [ab]	0.60 [b]
	CarbProt	75.50	249.50 [a]	48.63 [ab]	0.64 [a]
	Fat	75.50	242.38 [b]	43.63 [c]	0.58 [b]
	FatProt	75.63	249.25 [a]	52.50 [a]	0.70 [a]
	Prot	75.50	242.63 [b]	50.75 [a]	0.67 [a]
	ANOVA				
	Subst	NS	**	**	**
105	Basal	106.63	315.00 [c]	62.50 [a]	0.59 [c]
	Carb	106.63	340.63 [b]	77.63 [b]	0.73 [a]
	CarbFat	106.63	352.00 [a]	72.25 [c]	0.68 [b]
	CarbProt	106.63	352.00 [a]	81.00 [a]	0.76 [a]
	Fat	106.63	342.50 [b]	72.13 [c]	0.68 [b]
	FatProt	106.63	351.88 [a]	80.88 [a]	0.76 [a]
	Prot	106.63	342.63 [b]	78.13 [a]	0.73 [a]
	ANOVA				
	Subst	NS	**	**	**

** = $P < 0.001$; NS = $P > 0.05$; FL = Feed Level (% of ad lib); Basal=corn soy ; Carb=supplemented with corn starch; CarbFat=corn starch- corn oil supplemented diet; CarbProt=corn starch- isolated soy combination diet; Fat=corn oil supplemented diet; FatProt=corn oil-isolated soy combination diet; Prot=isolated soy supplemented diet; FI = Feed Intake; MEI = Metabolizable energy Intake; ;BW gain = Body Weight gain; FDEFF=Feed Efficiency

Table 9.Correlation of Kg with Biological Protein and Biological Lipid Values

Variable	R
BPV	0.67 (P < .01)
BLV	0.87 (P < .01)

Table 10. Energy need for live weight and energy homeostasis in male and female broilers limit fed from day 21through 29

		Body weight homeostasis		Energy homeostasis	
Sex [1]	**Diet**	**Maintenance (Kcal/IMBW$^{.67}$)**	**Live Weight gain (Kcal/kg)**	**Maintenance (Kcal/IMBW$^{.67}$)**	**Live Weight gain (Kcal/kg)**
F	A	127.6±14.2	3354±323	156.0±14.5	1.42±0.16
F	B	88.7±10.2	3508±182	122.3±6.30	1.34±0.05
F	C	125.1±9.3	3172±178	156.4±9.90	1.22±0.08
F	D	97.7±13.6	3623±248	131.0±11.1	1.46±0.10
F	E	114.7±13.7	3386±229	147.0±11.6	1.37±0.09
F	F	101.2±9.0	3174±155	130.3±7.9	1.24±0.06
F	G	97.5±14.2	3225±225	124.2±10.1	1.27±0.07
F	H	105.9±8.5	3101±135	139.2±7.4	1.20±0.05
F	I	102.1±10.1	3689±186	139.8±6.3	1.46±0.05
F	J	115.1±7.4	3152±134	146.0±6.5	1.23±0.05
Mean		**110.3±4.3**	**3262.5±75.2**	**142.0±3.9**	**1.28±0.03**
M	A	105.9±15.9	3333±316	138.6±14.4	1.31±0.13
M	B	109.7±7.4	2740±114	140.8±8.3	1.05±0.06
M	C	108.3±4.9	3305±90	136.7±5.0	1.30±0.04
M	D	113.1±8.9	3177±159	139.5±9.3	1.27±0.08
M	E	112.7±11.4	3233±194	139.5±9.8	1.29±0.08
M	F	102.5±8.8	3012±144	129.4±8.7	1.16±0.06
M	G	86.4±12.7	3409±202	116.5±11.5	1.39±0.08
M	H	106.2±5.4	3255±88	133.2±5.0	1.27±0.04
M	I	114.3±10.4	3231±191	146.3±5.3	1.23±0.04
M	J	98.3±10.7	3025±173	121.1±9.7	1.26±0.07
Mean		**108.1±3.9**	**3111.3±63.5**	**136.2**±3.4	**1.23**±0.03

[1] analysis revealed that there is no difference in maintenance energy need between the sexes and the data was pooled for subsequent analysis

Table 11. Energy need for maintenance and live weight gain per kilogram averaged over sex in broilers limit fed experimental diets from day 21 through 29

	Body weight homeostasis		Energy homeostasis	
Diet	**Maintenance (Kcal/IMBW$^{.67}$)**	**Live Weight gain (kg//kg $^{.67}$ /d)**	**Maintenance (Kcal/IMBW$^{.67}$)**	**Energy gain (kcal/kg $^{.67}$ /d)**
A	117.1±11.4	3292±238.7	156.0±14.5	1.42±0.16
B	104.4±9.2	3003±151.7	122.3±6.30	1.34±0.05
C	117.3±5.7	3226±106.6	156.4±9.90	1.22±0.08
D	108.1±8.0	3350±143.9	131.0±11.1	1.46±0.10
E	113.5±8.6	3302±145.1	147.0±11.6	1.37±0.09
F	102.2±6.3	3084±104.7	130.3±7.9	1.24±0.06
G	92.2±9.0	3313±143.9	124.2±10.1	1.27±0.07
H	106.0±5.1	3183±83.1	139.2±7.4	1.20±0.05
I	108.8±7.8	3458±143.3	139.8±6.3	1.46±0.05
J	108.1±8.4	3040±142.5	146.0±6.5	1.23±0.05
	107.8±8.0	**3225±140.4**	**142.0±3.9**	**1.28±0.03**

Table 12 Energy need for maintenance and live weight gain per kilogram averaged over sex in broilers limit fed diets supplemented with substrates from day 21 through 29

	Body weight homeostasis		Energy homeostasis	
Substrate [1]	**Maintenance (Kcal/IMBW$^{.67}$)**	**Live Weight gain (g/kg$^{0.67}$)**	**Maintenance (Kcal/IMBW$^{.67}$)**	**Live Weight gain (Kcal/kg)**
Basal	117.1±11.4	3292±239	147.9±10.9	1.33±0.11
Carbohydrate	112.6±6.6	3056±116	142.3±5.6	1.18±0.04
Carb-Fat	108.8±7.8	3458±143	144.2±6.0	1.34±0.05
Carb-Protein	106.0±5.1	3183±83	135.7±4.3	1.24±0.03
Fat	110.7±5.7	3327±99	140.2±5.3	1.33±0.04
Fat-Protein	108.1±6.7	3040±143	134.6±7.1	1.22±0.05
Protein	97.4±5.4	3198±88	126.0±4.9	1.26±0.04

[1] analysis revealed that there is no difference in maintenance energy need between the sexes and the dat was pooled for subsequent analysis

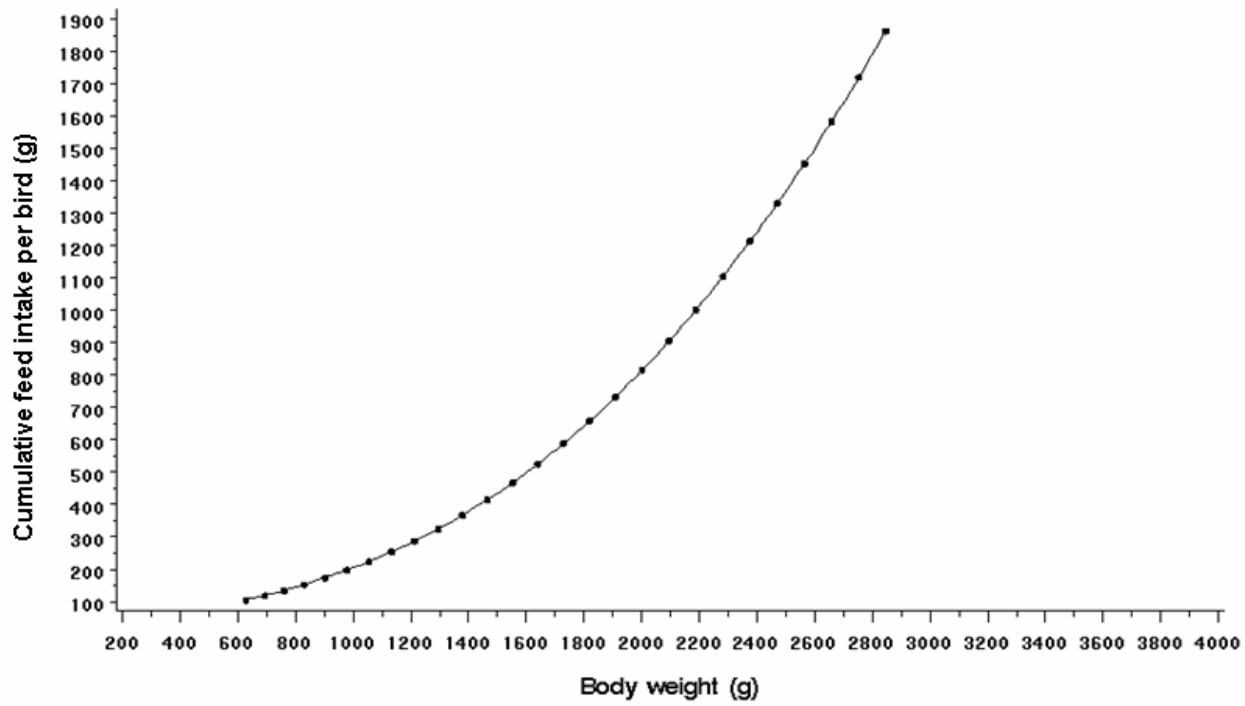

Figure 1. Plot of feed intake versus body weight of broilers throughout the growth curve. Fourth order regression yielded the equation utilized to estimate daily feed consumption for mixed sex birds allowed to consume feed *ad libitum*.
y = (-1.0638*10-12*BWT4) + (1.1058*10-8*BWT3) + (-0.00005493*BWT2) + (0.15974*BWT)
R2=.99 P < .0001; y = feed intake per bird per day. Data includes the period from 8 to55 days of age

Table 13. Effect of sex and supplemental energy level on performance of broilers limit fed from day 21 through 29 during the grower period

FL (%)	Sex	Supplement Energy Level	FI (g/d)	FI per IMBW (g/BW$^{.67}$/d)	MEI (Kcal/kg/d)	MEI per IBW (Kcal/kg/d)	BW gain (g/d)	BWgain per IMBW (g/BW$^{.67}$/d)	FDEFF
40	F	None	40.5	45.5	120.1^{c}	142.4^{c}	2.0^{c}	1.6^{c}	0.03^{c}
	F	175	40.5	45.6	126.4^{b}	151.1^{b}	12.0^{ab}	13.6^{ab}	0.30^{ab}
	F	350	40.5	45.5	133.6^{a}	159.5^{a}	11.6^{ab}	13.1^{ab}	0.29^{ab}
	M	None	40.5	45.6	119.8^{c}	142.6^{c}	9.6^{ab}	11.0^{ab}	0.24^{ab}
	M	175	40.5	45.6	126.6^{b}	151.0^{b}	9.5^{b}	10.6^{b}	0.23^{b}
	M	350	40.5	45.6	133.6^{a}	159.5^{a}	12.9^{a}	14.5^{a}	0.32^{a}
		ANOVA				P			
		Sex	NS	NS	NS	NS	NS	NS	NS
		Energy	NS	NS	**	**	**	**	**
		Sex x Energy level	NS	NS	NS	NS	*	*	*
75	F	None	75.5	85.3	222.8^{c}	267.9^{c}	34.5^{b}	38.5^{b}	0.45^{b}
	F	175	75.5	85.3	235.9^{b}	283.8^{b}	46.1^{a}	52.3^{a}	0.61^{a}
	F	350	75.6	85.4	249.5^{a}	299.6^{a}	46.8^{a}	52.8^{a}	0.62^{a}
	M	None	75.6	85.5	222.9^{c}	268.0^{c}	35.6^{b}	40.3^{b}	0.47^{b}
	M	175	75.6	85.5	236.3^{b}	283.6^{b}	50.5^{a}	57.1^{a}	0.67^{a}
	M	350	75.5	85.4	249.1^{a}	299.6^{a}	48.4^{a}	54.8^{a}	0.64^{a}
		ANOVA				P			
		Sex	NS	NS	NS	NS	NS	NS	NS
		Energy	NS	NS	**	**	**	**	**
		Sex x Energy level	**	**	NS	NS	NS	NS	NS
105	F	None	106.6	119.8	314.9^{c}	373.8^{c}	58.0^{c}	65.0^{c}	0.54^{c}
	F	175	106.6	119.6	333.3^{b}	396.0^{b}	70.5^{b}	79.1^{b}	0.66^{b}
	F	350	106.6	119.6	351.9^{a}	418.3^{a}	76.1^{a}	85.6^{a}	0.72^{a}
	M	None	106.6	119.6	314.9^{c}	373.6^{c}	65.5^{bc}	73.4^{bc}	0.61^{bc}
	M	175	106.6	119.6	333.3^{b}	396.1^{b}	78.0^{a}	87.5^{a}	0.73^{a}
	M	350	106.6	119.6	352.0^{a}	418.3^{a}	79.3^{a}	89.0^{a}	0.74^{a}
		ANOVA				P			
		Sex	NS	NS	NS	NS	**	**	**
		Energy	NS	NS	**	**	**	**	**
		Sex x Energy level	NS	NS	NS	NS	NS	NS	NS

* = P < 0.05; ** = P < 0.001 ; NS = P > 0.05; FL = Feed Level (% of ad lib); FI = Feed Intake;
FI per IMBW = FI / initial metabolic body weight; MEI = Metabolizable energy Intake; MEI per IBW = MEI / Initial Body Weight ; BW gain = Body Weight gain**;** BWgain per IMBW =BWgain / Initial Metabolic BW; FDEFF=Feed Efficiency

Table 14. Effect of sex and supplemental energy level on composition of broilers limit fed from day 21 through 29 during the grower period

FL (%)	Sex	Supplement Energy Level (kca/kg)	Protein Gain (g/d)	Fat Gain (g/d)	Ash Gain (g/d)	Water Gain (g/d)	Fat/Protein (F/P)
40	F	None	0.769^{c}	-1.821^{c}	0.033^{c}	1.881^{d}	-4.73^{c}
	F	175	2.757^{ab}	-0.459^{ab}	0.294^{ab}	8.259^{ab}	-0.295^{ab}
	F	350	2.671^{ab}	-0.588^{b}	0.272^{ab}	7.721^{ab}	-0.344^{ab}
	M	None	2.292^{b}	-0.588^{b}	0.220^{b}	6.389^{bc}	-0.474^{ab}
	M	175	2.248^{b}	-0.588^{b}	0.209^{b}	6.052^{c}	-0.925^{b}
	M	350	3.146^{a}	-0.588^{a}	0.327^{a}	8.947^{a}	-0.089^{a}
		ANOVA					
		Sex	NS	NS	NS	NS	NS
		Energy	**	**	**	**	**
		Sex x Energy level	**	**	**	**	**
75	F	None	6.597^{c}	3.019^{c}	0.901^{c}	22.751^{c}	.44^{c}
	F	175	8.738^{b}	4.879^{b}	1.215^{b}	30.246^{b}	.55^{ab}
	F	350	8.811^{b}	4.942^{b}	1.230^{b}	30.607^{b}	.55^{b}
	M	None	6.833^{c}	3.200^{c}	0.930^{c}	23.318^{c}	.48^{c}
	M	175	9.697^{a}	5.744^{a}	1.357^{a}	33.476^{a}	.59^{a}
	M	350	9.171^{ab}	5.283^{ab}	1.278^{ab}	31.634^{ab}	.57^{ab}
		ANOVA					
		Sex	*	*	NS	NS	*
		Energy	**	**	**	**	**
		Sex x Energy level	NS	NS	NS	NS	NS
105	F	None	10.345^{c}	6.331^{d}	1.456^{c}	35.973^{d}	.61^{d}
	F	175	13.317^{b}	9.137^{bc}	1.883^{b}	45.752^{bc}	.68^{bc}
	F	350	14.197^{a}	9.982^{ab}	2.013^{a}	48.743^{ab}	.70^{ab}
	M	None	12.233^{bc}	8.149^{cd}	1.725^{bc}	42.256^{c}	.66^{c}
	M	175	14.419^{a}	10.325^{a}	2.067^{a}	50.005^{a}	.71^{a}
	M	350	14.722^{a}	10.491^{a}	2.094^{a}	50.558^{a}	.71^{a}
		ANOVA					
		Sex	**	**	**	**	**
		Energy	**	**	**	**	**
		Sex x Energy level	NS	NS	NS	NS	NS

* = P < 0.05; ** = P < 0.001 ; NS = P > 0.05; FL = Feed Level (% of ad lib)

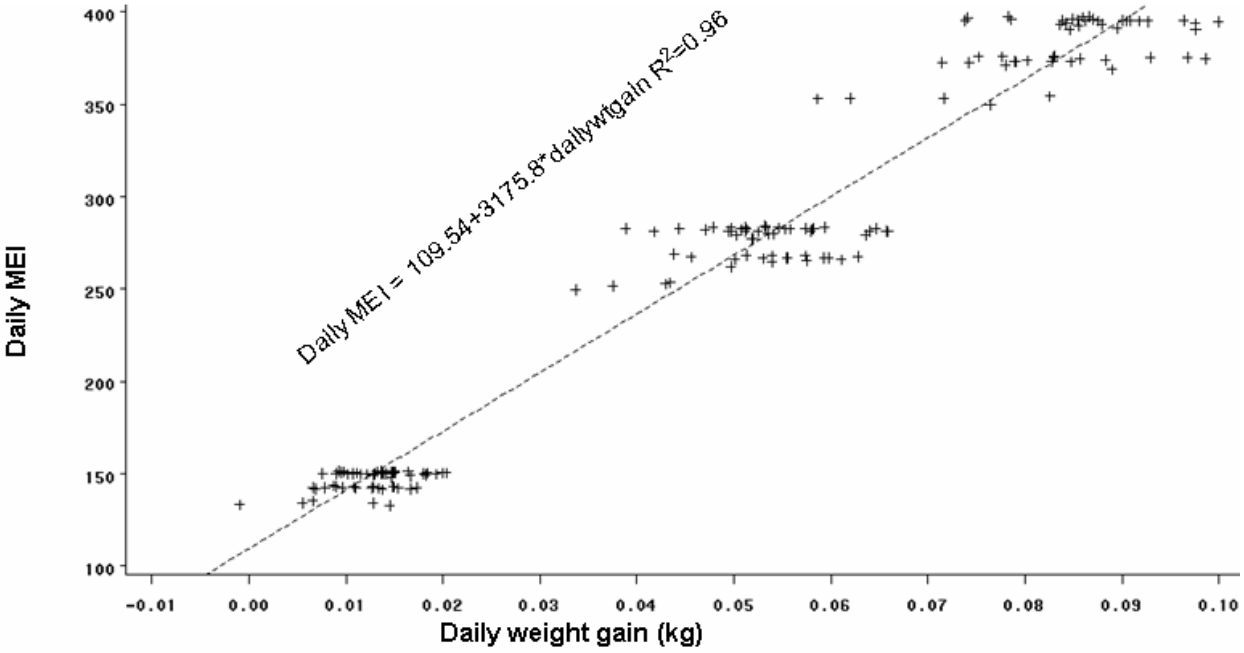

Figure 2. Plot of daily MEI (kcal/lBWkg$^{0.67}$) versus daily weight gain (kcal/lBWkg0.67) of broilers fed at 40, 75 and, 105% of ad libitum consumption.

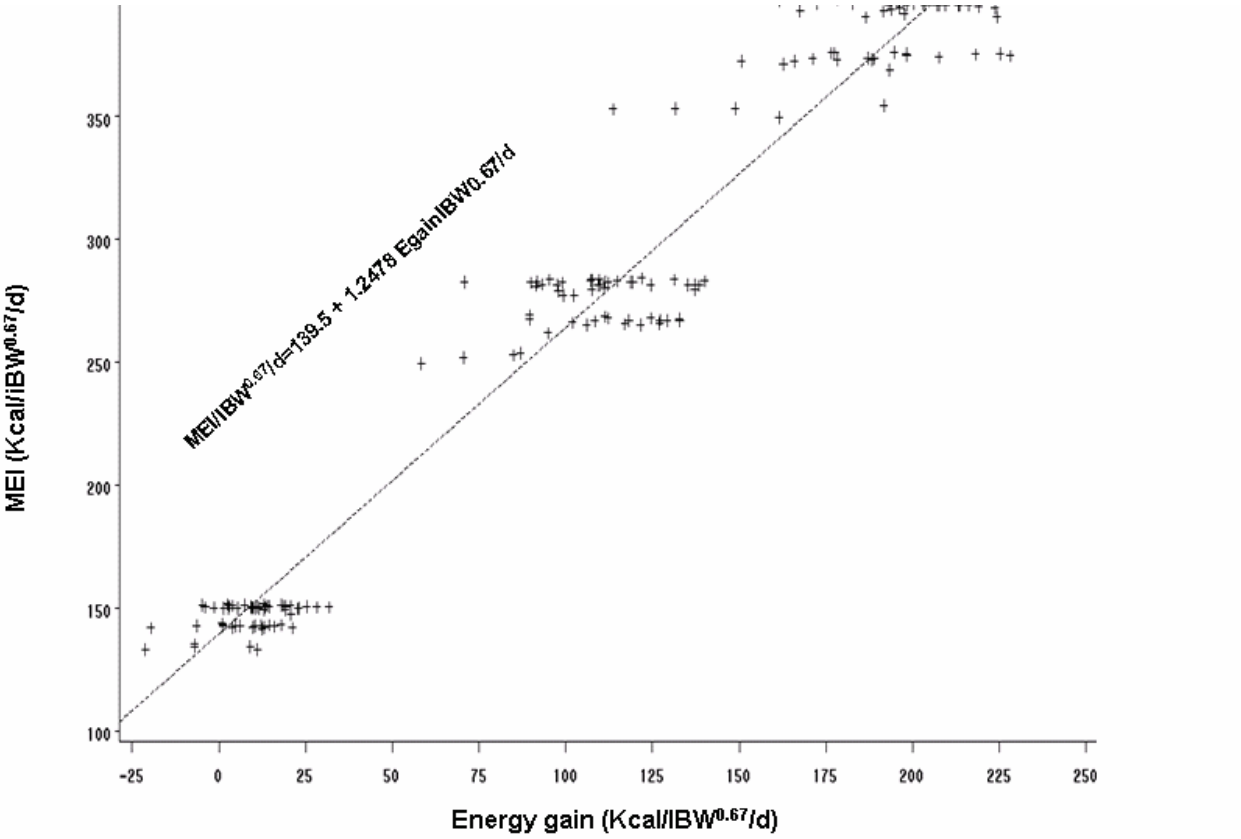

Figure 3. Plot of MEI (Kcal/lBW$^{0.67}$/d) VS Energy gain (Kcal/lBW0.67/d) of broilers fed at 45, 75, and 105% of ad libitum consumption

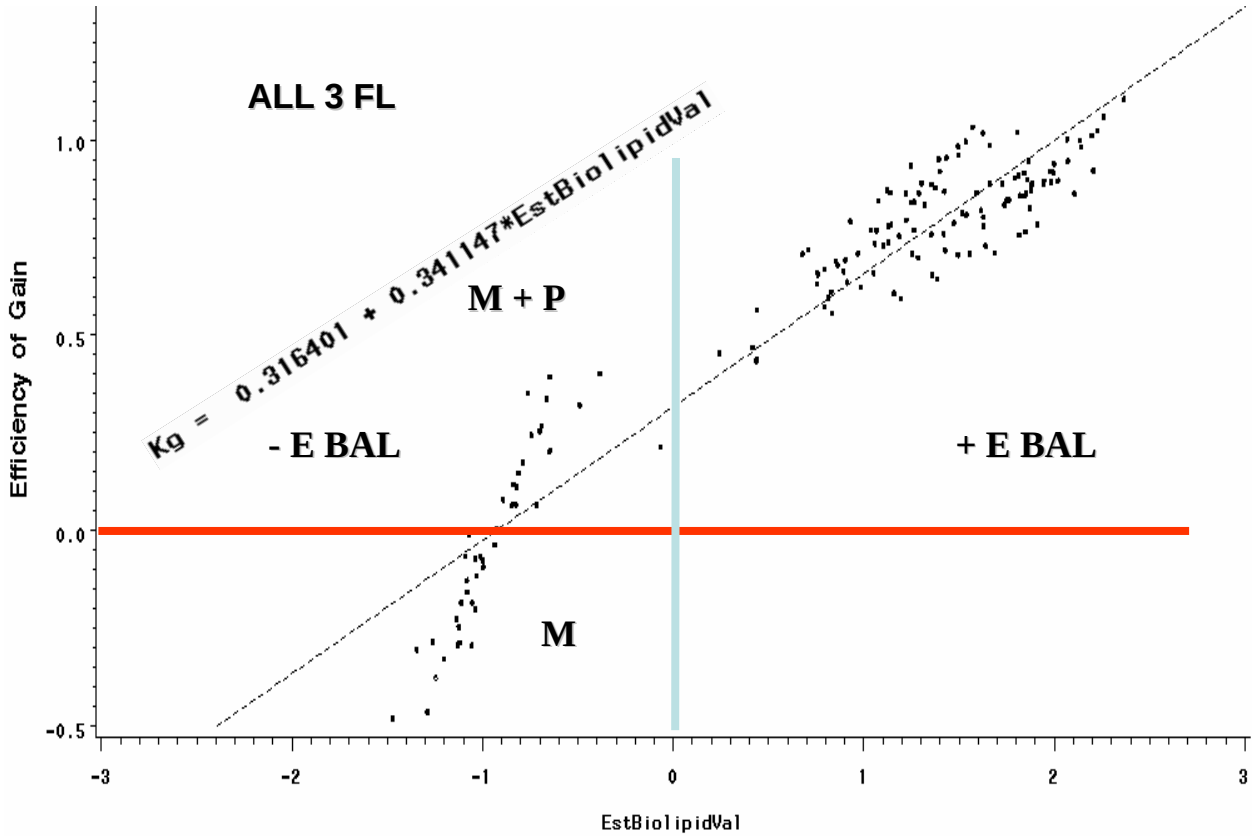

Figure 4. Plot of efficiency of gain versus biological lipid value

- E BAL = Negative energy balance; + E Bal = Positive energy balance; M = Maintenance;
M + P = Maintenance and production; Kg = efficiency of gain; EstBiolpidval = Biological lipid value calculated as lipid gain during feeding interval / digestible lipid consumption.

Table 15. Energy need for maintenance and live weight gain per kilogram averaged over diet in male and female broilers limit fed from day 21 through 29

	Body weight homeostasis		Energy homeostasis	
Sex [1]	**Maintenance (Kcal/IMBW$^{.67}$)**	**Live Weight gain (Kcal/kg)**	**Maintenance (Kcal/IMBW$^{.67}$)**	**Live Weight gain (Kcal/kg)**
F	110.3±4.3	3263±75.2	142.01±3.9	1.28±0.03
M	108.1 ±3.9	3111±65.5	136.20±3.4	1.23±0.03

[1] analysis revealed that there is no difference in maintenance energy need between the sexes.

Table 16. Effect of sex and supplemental energy level on energy balance of broilers 21 through 29 days of age

FL (%)	Sex	Supplement Energy Level	Toatal E for gain (Kcal)	Total E for maint (Kcal)	Kg E maintenance (Kcal/Kcal)
40	F	None	-102.3[b]	1005[ab]	2.39
	F	175	28.9[a]	1015[ab]	1.49
	F	350	60.1[a]	1026[ab]	2.73
	M	None	-128.1[b]	1066[a]	0.31
	M	175	28.3[b]	978[b]	2.02
	M	350	47.9[a]	1005[ab]	10.11
		ANOVA			
		Sex	NS	NS	NS
		E level	**	*	NS
		Sex x E level	NS	NS	NS
75	F	None	621[d]	1159	.83[b]
	F	175	802[bc]	1088	.95[b]
	F	350	892[a]	1112	.87[b]
	M	None	629[d]	1163	.88[b]
	M	175	783[c]	1098	1.09[a]
	M	350	866[ab]	1122	.93[b]
		ANOVA			
		Sex	NS	NS	*
		E level	**	NS	**
		Sex x E level	NS	NS	NS
105	F	None	1268[c]	1241	.74[c]
	F	175	1500[b]	1162	.85[bc]
	F	350	1607[a]	1205	.86[b]
	M	None	1232[c]	1264	.93[ab]
	M	175	1487[b]	1182	.96[a]
	M	350	1619[a]	1206	.90[ab]
		ANOVA			
		Sex	NS	NS	**
		E level	**	*	NS
		Sex x E level	NS	NS	NS

Table 17. Effect of sex and supplemental energy level on efficiency of energy use above maintenance in broilers limit fed from day 21 through 29

FL (%)	Sex	Supplement Energy Level	MEIforgain	E for maintenance	MEIforgain/IMBW	Efficiency of MEI use	Kg
40	F	None	132.6	828.6	140.44	-0.12	-.95
	F	175	237.81	773.89	268.06	0.08	.36
	F	350	277.96	791.54	310.92	0.06	.22
	M	None	103.00	855.07	111.46	0.03	.40
	M	175	245.42	767.72	275.91	0.03	.10
	M	350	274.04	794.87	308.46	0.10	.40
		ANOVA					
		Sex	NS	NS	NS	NS	*
		E level	**	*	**	**	**
		Sex x E level	NS	NS	NS	**	**
75	F	None	864.86	917.61	976.46	.29	.59
	F	175	1037.19	849.65	11171.49	.40	.73
	F	350	1128.25	867.27	1274.00	.38	.68
	M	None	862.02	920.93	976.94	.31	.63
	M	175	1033.73	856.24	116.23	.46	.84
	M	350	1115.84	877.49	1261.24	.41	.72
		ANOVA					
		Sex	NS	NS	NS	*	*
		E level	**	NS	**	**	**
		Sex x E level	NS	NS	NS	NS	NS
105	F	None	1537	982	1723	.37	.61
	F	175	1759	907	1973	.48	.73
	F	350	1875	939	2104	.49	.74
	M	None	1519	1000	1700	.46	.76
	M	175	1742	924	1954	.53	.82
	M	350	1873	943	2100	.51	.77
		ANOVA					
		Sex	NS	NS	NS	**	**
		E level	**	*	**	**	NS
		Sex x E level	NS	NS	NS	NS	NS

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