COMPONENTS OF ENERGETIC EFFICIENCY ASSOCIATED WITH BROILER AND LAYER PERFORMANCE

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Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
DOCTOR OF PHILOSOPHY
May, 2003

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ACKNOWLEDGEMENTS

I would like to express my sincere gratitude to my major professor, Dr. Robert. G. Teeter, for his guidance, patience, help and encouragement throughout my research and writing of this dissertation. I would also like to thank my committee members, Dr. S. Carter, Dr. J. G. Berry, and Dr. S. Vanhooser for their kind suggestions as members of my committee.

A special thanks is expressed to my colleagues of the OSU poultry farm, to the faculty members, fellow graduate students, lab technicians, and secretaries for their valuable knowledge, technical assistance, and friend- ship during my graduate study at Oklahoma State University.

To the family friends of Alice and Dr. Bill Howenstine, Bart Piotter and Dr. Debra Piotter Howenstine, and Steve and Becky Irby I express all my gratitude and appreciation for their generous hospitality, and invaluable assistances and cares they provided to my family since it came in the USA, until today.

My love and gratitude go to my late parents, for the endless support, encouragement, and living through the entire period of my life. Without their support, I could not have been where I stand today.

Finally, I would like to express my heart felt appreciation and love to my dear family: my wife, Beatrice N. Buzingo, and our beloved two daughters, Debra I. Buzingo and Delaine I. Buzingo for their love, encouragement, support, and understanding they gave me, and for always being there whenever I needed them.

FORMAT OF THESIS

This thesis presented in the Journal of Poultry Science style and format allowing for independent chapters to be suitable for submission to scientific journals. Four 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 and contains an abstract, introduction, materials and methods, results and discussion, and literature cited section.

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CHAPTER I

INTRODUCTION

The global increase of the poultry industry today is due to genetics, nutrition, veterinary science, and husbandry. These areas have increased the bird productivity, reduced its mortality rate and market age, while increasing its body weight and the edible part over the years. Yet, poultry growers and integrated processors in some parts of the world still meet some challenges that limit their goal. The expensive cost or scarcity of the main ingredients that make the diet of the bird, and the environmental heat stress hinder the efficiency and expansion of the poultry business.

The statistics indicates that during the last six decades, the bird has increased at the market age its body weight by 70%, and reduced its market age by 70% (12 vs 7 wk) ((Lacy, 2000). The same authors observed that the feed conversion and mortality rate have lowered by 100% each. In addition, the development of some pharmaceutical products and vaccines has greatly contributed to the increase of poultry production by suppressing some diseases that threatened to bring to the brink the poultry business. In the early 1940's, it was not uncommon to find half of the bird in production decimated by diseases such as Pullorum and Marek's diseases (Lacy, 2000).

The impact of genetic and nutrition on the poultry performance was highlighted in a study that indicated a genetically selected broiler over 35 years weighed at the age of

42 and 56 days respectively 4.3 and 3.9 higher than a non genetically selected birds at the same age (Havenstein *et al.,* 1994). Therefore, one of the objectives of the present thesis was to compare the growth performance, feed consumption and energy utilization between two broilers raised within an interval of five years of difference. The energy needed by the bird for the growth and the maintenance is provided by the nutrients contained within the ingredients that make the diets the birds are fed on. Common sense would suggest that birds fed on isocaloric diets that meet the NRC94 requirement (National Research Council 94) would have similar performance in weight gain, feed efficiency and energy retained. However, different studies have shown that the type and levels of the fiber and fat of the diets, the substrate chemical composition, and the gut microflora of the birds can cause differences in the growth performances of birds fed on isocaloric diets (Pirgozliev and Rose, 1999; Muramatsu et al., 1994; Sanz et al., 2000).

Corn, considered as the principal ingredient used in poultry feeds, is also a staple food in the diets of many people from the Third World countries. Therefore, the competition for corn consumption will likely limit the development of poultry business in those countries. Considering that several varieties of feedstuffs grow in different parts of the world where poultry is raised, we deem worthy to investigate the effects of several ingredients mixed in complex diet on broiler performance and energetic efficiency. This will likely provide rich source of effective alternatives to the main ingredients used in poultry nutrition, and eventually it will decrease the expenses allocated to the feed costs.

Heat stress remains a major factor that hinders the efficiency and expansion of poultry production during hot season in several parts of the world, especially in tropical and subtropical countries. Birds that are under heat distress reduced their feed consumption, and this will result in reduced body weight. In addition, heat stressed birds displayed an increased water consumption, a perturbed acid-base balance, and an altered carcass composition expressed (Teeter ad Belay, 1996; Howlider and Rose, 1987; Bottje and Harrison, 1985). Moreover, heat stress in broiler breeder and laying hens reduces egg production, egg weight, egg shell quality, and plasma calcium when compared to their counterparts raised in the thermoneutral environment (de Andrade et al., 1976). The same authors found that 86.6% of bird mortality recorded in heat stress environment was due to osteoporosis and/or osteomalacia. Therefore, we deem worthy to investigate the impact of heat stress in poultry, such as ways of heat dissipation and means of alleviating it.

Feed restriction is reported as one of the best approaches used in poultry nutrition to improve the flock growth and reproduction performances (Robinson et al., 1991; Yu et al., 1992). Applied as either qualitative or quantitative, feed restriction aims to control the increased bird body weight in an attempt to either offset the occurrence of metabolic disorders in the fast growing birds, or to improve the reproduction performance, lay yield and egg quality in the laying hens (Wilson et al., 1991; Yu et al., 1992). The program of lighting in poultry husbandry has proven to have a big impact on the bird performance: in improving the folk growth performance, feed efficiency while decreasing heat production. Compared to the light environment, birds held in dark produced less heat production, and during fasting or long transportation, they lose less body weight in catabolizing less tissues stored in order to meet the maintenance requirement. Nonetheless, the lighting pattern and feed restriction studies have provided mixed results in some cases, and this request further investigation

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CHAPTER II

REVIEW OF LITERATURE

IMPACT OF GENETIC SELECTION ON THE BIRD GROWTH

The body weight of the modern broiler has increased markedly during the last past decades. The literature indicates that a 1920's bird reached an average live weight of two pounds within 16 weeks, while a bird raised in 2000 had an average of 5.1 pounds in only 7 weeks (Lacy, M.P; 2000). Comparing the growth performance between two different broiler strains, Havenstein et al (1994a) found that the fast growing broiler Arbor Acres broiler (AA) weighed at 42 and 56 days respectively 4.2 and 3.9 higher than the Athens-Canadian Randombred Control broiler (ACRBC), a strain that has never undergone genetic selection along the years. Indeed, this shows that considerable achievements have been accomplished in the improvement of the broiler performance.

Genetic selection has been reported as the key factor in promoting the bird growth production in that it is responsible of 90% of the bird growth performance recorded (Havenstein *et al.*, 1994a; Marks, 1993). This observation was supported by a recent study of Gonzales et al (1998) who compared the growth performance among several contemporary broiler strains (Cobb 500, Arbor Acres, Avian Farms, ISA, Hubbard-Peterson, Ross, and Label Rouge) fed on identical diet. After 42 days, the authors 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 ($P < 0.05$), and the highest feed conversion ($P < 0.05$). Conversely, Ross broilers were numerically higher in both final weight and weight gain than the ISA and Hubbard-Peterson broilers, and higher ($P < 0.05$) than the Cobb 500, Avian Farms, and Arbor Acres, which were all similar to each other (Gonzales et al., 1998). The study indicated that the Ross broiler had the lowest FCR ($P \leq 0.05$) that was different from that of the Arbor Acres (1.77 vs 1.88), and numerically lower than that of the other 4 broiler strains.

IMPACT OF GENETIC SELECTION ON BIRD CARCASS COMPOSITION: The carcass composition of the genetically selected broiler has been affected over the years of selection (Chambers et al., 1981). The authors compared the carcass of a modern broiler raised in 1978 to that of a control raised in 1957 and found the modern broiler had a significant increase in carcass weight, nearly twice in percentage of legs and thighs, with though a significant decreased percentage in both nitrogen and ash, and lower percentage of wings when compared to the control. Similar significant changes in carcass composition in modern broilers were observed by Havenstein et al (1994b) who found that the 1991 AA broiler strains had 6 to 7 % higher yield in hot carcass weight, 4% higher in saddle and legs yield when taken as percentage of live body weight, and 3% higher in yield of total breast meat, when compared to the control ACRCB raised in 1957 ($P<0.05$). A significant higher percentage of both fat pads and carcass fat, with though lower size of both heart ($P<0.05$) and lung ($P<0.05$) were all observed in the modern broiler (AA) when compared to the ACRCB raised in 1957.

Broiler carcass composition changes over the ages (0-70 days) have revealed a linear growth in body weight (P<0.01), quadratic increase of the eviscerated carcass (P<0.01), deboned breast meat (P<0.01) and legs (Lesson and Perreault, 1992). In addition, the study showed that moisture and fat of the eviscerated carcass increased over the ages (P<0.01), whereas protein content decreased (P<0.01). This increase and decrease in percentage of protein and fat in eviscerated carcass recorded from broilers along the years, respectively of 44.9 and 39.4 % in 1969; 46.2 and 45.6 % in 1980; and 45.7 and 47.4% in 1992 suggest that genetic selection has lowered changes in broiler protein carcass when compared to changes in fat. It thus appears that a better improvement in bird growth rate was achieved rather than in meat quality throughout the years broiler selection. Nonetheless, considerations of the low percentage values of wings on eviscerated weight recorded along the years (13.5 in 1969, 12.9 % in 1980, and 11.3 in 1991), in contrast to the continuous increase in breast yield (23.1% in 1950; 26.6% in 1973, 31.3 % in1980 and 31.7% in 1992) suggest that there has been a continuous increased yield of the economically valuable parts of the broiler carcass along the period considered (Leeson and Summers, 1980; Moran and Orr, 1969; Leeson and Perreault, 1992).

The study of Havenstein and al (1994b) highlighted also the impact of nutrition on the broiler performance along the years in that the authors found that the 1991 diet increased the AA and the ACRB broiler body weight by an average respectively of 14% and 22% higher than the same broiler strains fed the 1957 diets.

IMPACT OF GENETIC SELECTION ON BIRD ORGAN SIZE: Observations of the modern broiler organ sizes have revealed that genetic selection has altered the broiler anatomy and physiology structures (Qureshi and Havenstein, 1994; Vidyadaran et al., 1990). Comparing the lung structure of the adult domestic fowl and its ancestor, the jungle fowl, Vidyadaran et al (1990) found that the weight specific volume of lung in the modern broiler was 20-30 % smaller than in its ancestor. In addition, they observed that the mean thickness of the blood-gas tissue barrier in the modern broiler was about 28 % higher than in the ancestor bird, while the anatomical diffusing capacity for oxygen of the blood-gas tissue barrier per unit of body weight was 25 higher in the non selected bird (ancestor) than in the fast growing one. As result, the slow development rate of the cardiovascular and respiratory systems, in conjunction to the fast growing muscular tissue of the modern broiler, has lead to the impairment of supplying enough oxygen so much needed to the quick growing muscle, and this has likely triggered or predisposed the bird to experience some metabolic disorders, such as ascites.

IMPACT OF GENETIC SELECTION ON BIRD MORTALITY: The incidence of mortality in fast growing broiler was assessed by Qureshi et al (1994) who compared the mortality rate between the non genetically selected 'ACRBC (1957)' vs the selected broiler strain "AA (1991)" at 42 days of age. The authors found that the bird respective mortality was of 3.3% (ACRBC) and 9.1% (AA), underlying thus the negative impact of genetic selection on broiler mortality. Further observations on the cause of mortality revealed that most of the recorded mortality in AA broilers was due to ascites and flip-over (Qureshi et al., 1994). The higher mortality in fast growing birds was also reported by Gonzales et *al.*(1998) who found that the broiler strain displaying the lowest growth performance rate (Label Rouge) had the lowest mortality rate among all strains. On the other hand, the best productive strain (Ross) displayed the highest incidence of mortality (12.96%) that was numerically higher than that recorded in the rest of fast growing strains. The analysis of the mortality data indicated that barring the Label Rouge case, more than 50% of the mortality was due to metabolic disorders. Further analysis has indicated that the ratio of right ventricle to the total ventricle (RV:TV) from the fast growing strains (0.26-0.33) far exceeded 0.25, an index of right cardiac hypertrophy secondary that trigger ascites condition (Julian 1993, Shlosberg et al., 1992), whereas, the RV:TV in the Naked Neck strain ratio was always lower than 0.25.

CONTRIBUTION OF NUTRITION ON THE GROWTH OF THE MODERN BROILER: While genetic selection remains the key foundation of the flourishing broiler production the poultry industry is enjoying today, nutrition has played an important role in providing rich nutrients from the same feed source and improving feed efficiency.

ENZYMES

GLUCANASE AND XYLANASE: The discovery and utilization of various enzymes in broiler nutrition have greatly contributed to the increase of the broiler growth performance and efficiency of nutrient utilization. Investigations conducted within the birds fed diets containing either barley or wheat have shown that these ingredients are responsible of increased digesta viscosity that has deleterious effects on the fed birds Indeed, the viscosity of the diet (digesta) reduced the diffusion rate of both endogenous enzymes and nutritional substances, and increased both the rate of feed passage and depth of the unstirred water layer adjacent to the epithelial lining of the small intestine that hamper the nutrient absorption (Classen, 1996). In addition, the cell walls that contain either arabinoxylan or β -glucan may act as physical barrier to endogenous enzymes, resulting in reduced nutrient utilization (starch and protein) that remained encapsulated within the endospermal cells. However, supplementation of xylanase and β-glucanase in the above diets has resulted in significant increases of nutrient absorption, improved growth rate and increased efficiency of feed utilization in the fed birds when it was compared to the control (Bedford, 1996; 2001; Choct and Annison, 1992; 982).

Even corn, considered as the king of the cereals because of its highest content of both digestible nutrients and energy level among all cereals, studies have shown that broilers fed corn-soybean diets supplemented with 01% Avizyme® 1500, a mixture of an enzyme comprising xylanase, protease and amylase, had after 42 days significant higher body weight gain and feed efficiency ($P<0.05$) than the control (Zanella et al., 1998). In addition, the digestibility of various amino acids such as threonine, serine, glycine, valine, and tyrosine was significantly improved ($P<0.05$). In the same line, supplementation of α-glucosidase in the corn-soybean diet fed broilers- in order to break down the α- glucoside (stachyose and raffinose) present in the soybean as the bird's intestinal mucosa lacks α-glucosidase enzyme activity - has resulted in significant improvement in broiler TMEn and feed conversion ($P<0.05$) with lower mortality rate ($P<0.05$) when compared to the control ones (Knap et al., 1996; Kidd et al., 2001).

PHYTASE: Phosphorus content of cereal grains appears as phytate, a form that makes up nearly 70% of the total phosphorus content and possesses little or no biological availability to the bird growth purpose (Nelson, 1993; Summers, 1997). This phytate forms an insoluble complex of protein-metal-phytate that reduces the absorption of protein and essential minerals such as Ca, Mg, Fe, and Zn (Ledoux et al., 1996), impairing various normal metabolic functions within the bird organism. In addition to its chelating properties, phytate and its different products of enzymatic hydrolysis inhibit several enzymes such as pepsine, and α-amylase leading thus to a reduced digestibility of protein, starch and lipids. As result, there will be impairment of nutrient availability for the bird growth. However, the utilization of phytase, and especially a cocktail of enzymes used to dephosphorylate the dietary phytate (in order to alleviate cases when carbohydrate, fat or other nutrients occlude phytase and hinder the enzyme access) has resulted in significant increases in nutrient retention such as P, Ca, nitrogen and amino acids, bird weight gain, feed conversion, AME in the fed broilers, and improvement of the issue related to the eutrophication within the environment (Ravindran et al., 1999; 2000; Ledoux et al.,1995, Zyla et al., 2000).

Recent investigation conducted by Scheideler and Ferket (2000) has also highlighted the beneficial effect of phytases in bird nutrition by showing that Ross chicks fed diets supplemented by phytase had after 7 weeks significant higher body weight ($P<0.004$), feed conversion ($P<0.006$), percent livability ($P<0.004$), leg quarter weight ($P<0.007$) and lower tibia dyschondroplasia ($P<0.002$-0.01) when compared to broilers fed diets non supplemented with the enzyme.

ENERGY AND PROTEIN: Qualitative and quantitative adjustments of broiler diets in nutrient levels such as energy and protein have resulted in some controversial responses on the growth performance and carcass composition of the fed birds. Several authors

(Twining et al., 1974; Moran et al., 1978) have reported that birds fed on a low protein diet from 1 to 4 weeks failed to reach the same performance as a bird fed the required dietary protein, but the 2 birds reached the same body weight and had equivalent feed conversion at 6 weeks once the they were all fed the complete diet during the last 2 weeks. Nevertheless, the birds initially fed the low protein diet displayed significantly reduced carcass protein and increased carcass fat when compared to the full fed protein diet, and this was likely due to the effect of overeating in order to get the limiting amino acid required to get the optimal performance. On the other hand, Waldroup et al. (1976) sustained that birds fed on diets formulated to meet essential amino acids within practical feeding stuffs reached the optimal performance, a proposal rejected by Jensen (1991) who stated that birds need a minimum quantity of protein intact in the diet in order to reach the best growth performance. However, the efficiency of low protein diet in producing optimal efficiency in both growth performance and higher protein utilization with a 26% reduction of nitrogen excretion, was obtained in a study with birds fed low protein diets supplemented with synthetic essential and non essential amino acids that matched the protein level of the control (Deschepper and De Groote, 1995).

ANTIBIOTICS: The antibiotic growth promoters modify the bird intestinal microflora by acting specifically on Gram positive organisms that compete with the bird nutrients, elicite immune response that depresses the bird's appetite, cause some diseases in birds such as necrotic enteritis, degrade the bird digestive enzymes, and increase the size of the intestinal tract by producing stimulatory compounds (i.e. polyamines and volatile fatty acids) that reduce the nutrient efficiency in the birds (Bedford, 2000). Therefore, the use of antibiotic growth promoters in broiler nutrition has considerably improved the bird's nutrient retention, growth performance and health status. Products such as zinc bacitracin and virginiamycin have shown to significantly improve growth performance and nutrient retention in the fed broilers by suppressing the pathogenic bacteria, (inhibit cell wall formation, protein synthesis, and increase bacteria susceptibility to the bird's own immune system), reducing the intestinal inflammation and thinning the gut wall, suppressing the formation of ammonia, toxic amines, and other growth depressing stressors, and by reducing both energy intake and heat increment while increasing both caloric gain and caloric efficiency in the fed birds (Bernstein 1994; Huyghebaert and DeGroote, 1997; Belay and Teeter, 1993; Manner and Wang, 1991). On top of that, virginiamycin is reported to have a unique property among all antibiotics of protecting both dietary energy (it reduces carbohydrates breakdown to lactic acid by 83% in crop and 94% in small intestine) and lysine from microbial degradation (Davis, 1998). Nonetheless, serious concerns are arising today all over the world about the use of the antibiotics in animal nutrition, because of their cross resistance or multiple resistance to other related antibiotics used in human medecine (Witte, 1998; Levy, 1998). As results, several countries have banned the use of antibiotic in animal feed despite a lack of clear cut scientific supporting reasons, whereas other countries have restricted or limited their use on their land (Muirhead, 1998). This crucial concern has lead investigators to orient their research towards other means that would efficiently replace antibiotics as growth promoters in animal nutrition.

ALTERNATIVES TO ANTIBIOTICS AS GROWTH PROMOTERS

Several alternatives to antibiotics as growth promoters have been developed, tested, applied in broiler diets where they have efficiently contributed to the growth performance and welfare of the fed birds (Hertrampf, 2001; Mlot , 2001)

DIRECT FED MICROBIALS: Formerly known as probiotics, these products are selected and concentrated viable counts of microorganisms that once applied in the host organism and after they adhere, grow, and multiply on the intestinal epithelial cell of the host, they beneficially affect it by improving the property of its indigenous microflora (Fuller et al., 1989; Vanbelle, 1990). Beside their antagonistic activity and competitive inhibition towards pathogen bacteria (Lee, 1999), direct fed microbials supplemented in broiler diets have resulted in several beneficial effects to the fed birds: increased bird body gain, feed conversion, N, Ca, P retention, and enzyme synthesis, reduction or suppression of detrimental enzymes (glucuronidaes, nitroreductase and azoreductase) involved in the production of active carcinogens from innocuous procarcinogens present in animal feed, and neutralizition of enterotoxins produced by pathogenic bacteria that impair the immune body system of the birds (Lee and Lee., 1990; Jin et al., 2000; Goldin and Gorbach., 1977, 1984., Nahashon et al., 1994 ; Scheideler, 1993; Mohan et al., 1996).

OLIGOSACCHARIDE: Carbohydrates such as β-glucans are suggested as promising growth promoters to be used in broiler diets where they act as immunostimulants to enhance the bird defense systems. These products activate the phagocytic leucocytes by binding them to specific receptors, thus increasing the animal resistance to various infections (Hertampf, 2001). One of this compound is a mannanoligosaccharide (MAO) known under the commercial name of “Bio-Mos”. It has been applied in broiler diets and has provided similar growth performance (weight gain, feed conversion) as those of the bird fed diets supplemented with zinc bacitracin (Alltech, 1998). In addition, MAO is reported to specifically serve as a source of nutrient for the beneficial bacteria while starving the pathogenic ones. Moreover, mannose sugars are reported to confuse pathogenic bacteria whose receptors bind mannose and fail to attach and colonize the gastrointestinal tract, and this will result in a wash off of the pathogens through the gastrointestinal tract, while leaving no harm to the fed broiler (Alltech, 1998).

MYCOTOXIN BINDERS: Chinoptilolites, zeolites with negative charges, are non-nutritive inert absorbent products used in broiler nutrition as efficient detoxifiers and growth promoters with effects of improving bird growth performance, feed efficiency and immune function usually inhibited by mycotoxins (Kubena et al., 1993, 1999; Huff et al., 1992; Oguz and Kurtoglu, 2000). Once in the broiler diets, these silicates are activated by the chyme liquid of the bird tract digestive, then act selectively on toxins, especially NH_3 and mycotoxins whereby through the ion exchange mechanism, they bind on cationic charges of the toxins, forming a stable complex of zeolite loaded with the respective toxins. The complex zeolite-mycotoxin formed will be then excreted with the feces; thus reducing mycotoxin absorption and contributing to the detoxification of the bird organisms (Ledoux et al., 1999). Kubena et al. (1993) and Scheideler et al. (1993) have reported that broiler fed diet containing both aflatoxin and chinoptilolites increased body weight from 10% to 19% when compared to birds fed diets containing only aflatoxins. Further and ample investigations of these promising non-toxic products in broiler nutrition are worthy to be conducted and determine their eventual impact on the maintenance requirement and net energy efficiency resulting from their utilization.

DIVERS: Mlot (2001) suggested that as an alternative to antibiotics in broiler nutrition, tweaking the bird' immune system (i.e. creating antibodies that act against the target that regulate the growth) may provide reliable means to stimulate the bird's growth while staving off infections. In this regard, the same author reported that the use of antibodies in chickens to block the effect of cytokines (regulator molecules produced by the immune cells) that can cause some wasting, has experimentally resulted in faster bird growth. He further stated that the chicken interferon gamma, an immune cell product, is being tested as an alternative to antibiotic therapy for infections and to promote weight: this highlights that a rich and potential arsenal of alternatives to antibiotics use in animal nutrition might be available in the near next future, once the field of experimentation will be completed.

ALLEVIATION OF FAST GROWING BROILER ABNORMALITIES BY NUTRITIONAL PRACTICES: In spite of the current saying that states that "genetic creates the bird and the nutrition starts with it", implying that the nutritionists allow the bird only to express its genetic potential, researches have shown that not only nutrition has greatly contributed to the increased bird production in providing more available and efficient nutrients present within the same feed source, but also it has alleviated some crucial genetic flaws recorded in broilers undergone heavy genetic selection. Leg problems, metabolic disorders such as ascites and fatty liver kidney syndrome (FLKS), increased carcass fat deposition, and poor reproduction performances are some of the broiler abnormalities resulting from intense genetic selection (Whitehead, 1998; Robinson et al., 1992; 1995). Investigations conducted on the broiler metabolic disorders have revealed that the fast growing broiler abnormalities such as tibia dyschondroplasia

(TD) and FLKS can be successfully alleviated or reduced by supplementing the diets respectively with vitamin D metabolites such as 25-hydroxycholecalciferol (25-D) or 1,25-D (Rennie and Whitehead, 1996) and biotin (Bannister et al., 1975; Whitehead et al., 1976).

Maxwell & Robertson (1997) reported that a nutritional plan of feed restriction based on skipping a day (no feed on days 7, 9, 11, and 13) applied in the broiler at the early age has not only produced at the market age birds of the same body weight as the full fed one, but also it has reduced the ascites incidence from 30% to 5%. Tanaka et al. (1995) also found that the skip-a-day feeding program applied in broiler chicks resulted in a significant reduction of abdominal fat with a full recovery in body weight when compared to the full fed broilers.

IMPROVEMENT OF ENERGY UTILIZATION IN BROILER OVER THE YEARS OF BREEDING PROGRAM: An examination of Agrimetrics statistics for dietary metabolizable energy (ME) contents fed to growing broilers indicates, while days needed to produce a 2.5 kg bird have dropped by 7 in 10 years, that the mean dietary ME content has fallen from 3220 kcal/kg in 1989 to 3150 kcal/kg in 1999. Not only is the industry now capable of feeding lower energy ration, but also it is done so with improved efficiency. For this to occur, the rations net energy (NE) value must be improving. Indeed, recent modeling in our laboratory of the 94 vs 99 commercial broilers (see Chapter I) has shown that while ME remained constant during a 5 year span, NE for the 99 commercial broiler improved by 6% when compared to the 94 broiler. This 6% change in NE content was associated with a decline in dietary ME by the US Poultry industries over the same time period. The poultry industry is placed in a reactionary position whereby dietary changes are in response to evolving bird efficiency. Failure to make changes places company in a position of producing fat carcass.

The bottom line for any energy evaluation scheme is that birds fed equal quantities of energy, regardless of source, should extract a predicted amount. However, various investigations have shown that birds raised on an isocaloric diet with equal metabolizable energy displayed significant different net energy deposition (Collier et al 1996, Muramutso et al 1994). Therefore, the aim of this study is to investigate the effect of different isocaloric and izonitrogenous diets composed of several different ingredients in mixture on the bird performance and energetic efficiency

METABOLIZABLE ENERGY VS NET ENERGY: The value of a feedstuff, to meet bird energy need, is generally evaluated on the basis of its metabolizable energy content (ME; Noblet et 1993; Sibbald., 1980). Metabolizable energy accounts for all energy losses save heat production. In contrast, net energy (NE) accounts for ME and heat production and is considered as the feedstuffs “true energy” in that it is the energy quanta used for maintenance, tissue accretion, egg production and activity. Any variability in feedstuff heat production would be expected to create uncertainty in actual energy value. Several studies have demonstrated that feedstuff ME value potentially varies with bird age (Zelenka, 1997), amount and nature of food passing the GI tract (Hartel, 1986); environment or site where the cereal is grown (Scott et al., 1998; Mollah et al., 1983; Longssaff and McNab.,1986), period of growth (Carré et al., 1991), cereal type and variety (Brown, 1996; Classen, 1996) as well as method or techniques of analysis (Scott et al., 1998; Hartel,1986).

Metabolizable energy of an ingredient is usually determined in special conditions, with the feedstuff being either force-fed alone (TME) or incorporated in simplified diets given to the birds (AME). It is generally assumed that no interaction exists among the ingredient components as synergism or antagonism; and this has been criticized as being a problem (Frape and Tuck, 1973; Noblet et al. 1993). Therefore, it will hardly predict accurately the energy retained or energy deposited (NE) by the bird. In this regard, a study done with swine nutrition using a technique of multiple regressions has shown that the fiber components of the diets not only negatively affected diet digestibility, but also decreased the digestibility of other nutrients (Noblet et al. 1993). Prediction equations generated by this technique (Noblet et al. 1993) have revealed that the digestible energy (DE) and ME tabular energy overestimated energy value of feed with high amounts of protein or fiber, while it underestimates the energy value of high starch and fat diets. This has also been previously reported by De Groote (1975) who found that the ME based system underestimates utilizable energy of fats /fat-rich feedstuffs and carbohydrates while overestimating protein-rich feedstuffs.

Factors such dietary's substrate chemical composition, processes associated with nutrient metabolism, ingestion, excretion and absorption, gut micro flora, and both nature and level of fat within the diets all have an impact on the net energy retention that the metabolizable energy is unable to either predict or detect (Muramatsu et al., 1994, Muelen et al., 1994, Collier et al., 1996).

IMPACT OF SUBSTRATE ON THE BIRD ENERGY RETENTION: Mittelstaedt et al. (1987) have demonstrated that birds raised on equivalent supplemental ME quanta, derived from different sources, and exhibited significant differences in energy gain. The authors reported similar amounts of protein gain with differing fat retention between the treatments. Care was taken to maintain similar ratio of indispensable amino acid/ME calorie. Substrates (soybean oil, corn starch, gelatin) were added on top of the 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 gain energy (30 % and 16 %) and fat gain (112% and 85%) than birds fed gelatin as the supplemental energy source. The study highlighted the impact of substrates (ingredient composition) 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.

Similar to Mittelstaeldt's finding, a general lack of ME accuracy to predict bird NE was shown in a broiler study with birds fed 6 feeds containing equivalent amount of vegetative fat, protein and starch concentrations that all meet the bird nutritional requirement (Collier et al., 1996). At the end of the experiment, the authors didn't detect differences in AME; however, they reported significant differences in both energy retention and food conversion ratio among the birds. In the same context, a related study conducted with swine fed two starches having similar ilea digestibility, indicated differences in net utilization of glucose produced by *in vivo* digestive hydrolysis (Meulen et al., 1997). The fact that the two starches differed in the amount of lactate and volatile fatty acids produced in small intestine suggested that bacterial fermentation in the small intestine, was likely responsible of changing the amount of utilizable net energy derived from the feed that the ME determinations would not be able to detect. In the same context, Muramatsu et al. (1994) conducted a study with both germ-free and conventional chickens given an equivalent dietary ME intake and found at the end of the experiment that the conventional chickens had a reduction of 16% in net energy.

Further related investigations have found that diets formulated as either ME or NE requirement (NE was set equal to 0.75 ME on the basis of a previous study) failed to provide similar growth performances in the fed birds (MacLeod et al., 1998). This suggests that heat increment or energy associated with absorption, excretion and secretion likely differed among the isocaloric diets, thus resulting in different NE. Again, the study underlines the lack of accuracy and reliability of ME in predicting NE. The results showed that birds fed diets formulated on the basis of NE had a significant higher mean body weight ($P<0.001$), feed conversion efficiency ($P<0.001$), and both TME and NE intake cumulative significantly higher ($P<0.01$) than the birds fed ME formulated diets, while these birds under the 2 systems had an initial equal ME energy intake. In the same context, Pirgozliev et al. (2001) fed female Cobb broiler chickens with 12 isoenergetic diets made of 6 different wheat cultivars having nearly equal proximate nutrient composition, and they didn't find any significant differences in the apparent metabolizable energy (AMEn) of the wheat samples. However, they observed a significant difference in bird carcass energy retention among the wheat cultivars, stressing a large difference in wheat cultivars to efficiently utilize AMEn for energy retention. Nonetheless, a significant negative linear relationship between the wheat water extract-viscosity (expressed in log terms) and the energy retention/AMEn values from wheat intake was observed. As the increased digesta viscosity (expressed by a higher wheat water-extract viscosity) gives rise to a proliferation of microflora in the small intestine that leads to increase the quantity of nutrients to be fermented in the lumen of the digestive tract (Annison, 1993, Bredford et al., 1996), it is likely that the heat increment of digestion in the wheat cultivar's diets with higher digesta viscosity will be increased in the detriment of quantity of MEn available for carcass of carcass energy retention.

IMPACT OF DIETARY FAT (OIL) ON ENERGY RETENTION

Soybean oil added within the broiler diet (30 g/kg) above the required dietary fat level has resulted in an increase in weight gain (6.9%) and net energy deposition (12.1%) not correlated to the increase in the ME in those broilers fed the diet supplemented with extra oils when compared to the birds raised on the normal diet (Nitsan et al., 1997). The beneficial effect of this extra lipid caloric in diets seems to result from the direct transfer of the fat acids to the body tissues, when a little excess of dietary lipid is added within the diets (NRC 94, Nitsan et al., 1997). In this way, the normal process of tissues lipid synthesis that requires heat production, and therefore reduces bird net energy will be reduced, whereas net energy will be increased. Shimomoro et al. (1990) also reported that the type of fat or oil supplemented in diets to have a big impact on both the energy retention and its partitioning: mice and rats fed isoenergetic diets that contained either unsaturated vegetable oil or beef tallow as major source of fat retained less energy in the unsaturated fat supplemented diets when compared to the saturated fat one. It is believed that diets rich in polyunsaturated fatty acids lead to a high rate of *in vivo* fat oxidation that results in lower body energy accumulation when compared to the diets supplemented with saturated fatty acids. Guillaume et al. (1979) have previously reported lower energy accretion in animals fed diets supplemented with polyunsaturated fatty acid, when compared to those fed diets that contained saturated fatty acids. A recent investigation (Sanz et al., 2000) conducted on energy retention in broilers fed isoenergetic diets with either saturated or polyunsaturated sources of fat has also indicated that while fat source did not show any difference in bird weight gain, final body weight, intake, food to gain ratio, yet broilers fed on saturated fatty acid diets displayed higher whole-body fat retention and lower protein accretion than those fed diets supplemented with unsaturated fatty acids.

Previous investigations of the same authors have shown that saturated fatty acid supplemented diets resulted in both broiler with significant higher level of abdominal fat pad accumulation (Sanz et al., 1999), whereas Su and Jones (1993) have observed rats with both higher body fat gain and lower body lean mass from diets with saturated fatty acid, when compared to their counterparts fed on supplemented unsaturated fatty acids diets. Pichasov and Nir (1992) suggested that during the biochemical process of fat acid synthesis, dietary polyunsaturated fatty acids modulate the 9-desaturase complexes that cause a reduction in synthesis of oleic acid and, this will lead to a decreased process of lipogenesis.

Investigations conducted by Noblet et al. (1993) and De Groote (1975) respectively in swine and poultry have indicated that both DE and ME tabular energy system of the feedstuff overrated the energy values of fiber and protein content, while underrating the energy values of the feedstuff content in starch and fat.

DIETARY AMINO ACID RETENTION: Research conducted with essential amino acids (Baker and Chung, 1992; Baker and Edwards, 1999) have indicated that the efficiency of broiler amino acid retention in the birds varies with the respective amino acids. This may depend on the intrinsic properties of each amino acid such as: rate of turnover within the various pools (tissues, free amino acid, liver storage proteins, blood), competition for absorption or some other impairment in the retention process.

EVOLVING FEEDSTUFFS: Today, transgenic plants are being engineered to increase the crop yield and to provide resistance to the plant against biotic agents. However, these plants may incidentally have different chemical composition when compared to their traditional counterparts. Such difference may lead to a variation in energy content and subsequent bird performances. Brake and Vlachos (1998) observed a significant increase in feed conversion and yield of *Pectoralis minor* breast muscle from broilers raised on the transgenic corn diets. Predictive equations for NE may enable such changes to be better accounted for. Therefore, for an effective and reliable evaluation of the broiler net energy, the chemical composition of these new-engineered crops need to be known before to determine the diet ME.

FIBER EFFECTS: Miller et al. (1994) reported that dietary fibers possess a negative impact on diet and its true metabolizable energy (TME). The authors reported that barley within diet containing ADF levels from 2.1 to 12% reduced TME from 3301 to 2630 kcal/kg (26%) in poultry, while an increased of ß-glucans of 3.4 to 6.8% decreased also barley TME from 3248 to 2855 kcal/kg (14%).

The negative impact of fiber level on energy availability in fed birds was also highlighted by McNab et al. (2000) in a study with chaya leaf meal (CLM) and wheatleaf (WL) that contained respectively: CP (27 and 16%), EE (6.7 and 3.6%), CF (14.4 and 4.5%), NDF (20.2 and 29.6%), and ADF (20.2 and 11.7%), with similar gross energy (16.8 MJ/kg). The result showed that not only CLF had significant lower TME than WL (5.76 vs 8.39 kj/kg), but also was its net energy efficiency of TME utilization (k=0.64 vs 0.86). On the other hand, heat increment in CLF was 1.7 higher than in the WL.

Feedstuffs are known to contain anti-nutritive substances that impede nutrient availability for growth and production purposes (Bedford, 1996; Annison and Choct, 1990). In this context, wheat and barley grains are known to possess in their cell walls respectively arabinoxylans (pentosans) and ß-glucans (Annison and Choct 1990), soluble non starch polysaccharides (NSP) that are not only impervious to enzymatic attack in the broiler- and thus prevent the endogenous enzyme access to the nutrient- but also increase the digesta viscosity resulting in detrimental effects on bird performance, impaired nutrient availability (due to reduced nutrient transport, diffusion and absorption) and decreased metabolizable energy (Bedford and Morgan, 1996., Choct and Annison, 1992). Smits and Annison (1996) have reported that both soluble pectic substances and gel-forming gum contents of some feedstuffs increase the thickness of the aqueous barrier adjacent to the intestinal mucosa. Such changes may occur and impair nutrient absorption efficiency. However, xylanase and ß -glucanase enzymes supplemented respectively to wheat and barley-based diets have alleviated the problem and increased ME values (Bedford, 1996).

OTHER FACTORS: Cottonseed meal contains gossypol, a polyphenolic pigment that binds iron in the diet, bloodstream and in the egg yolk. Therefore, birds fed diet containing cottonseed meal experience problems such as development of iron deficiencies and formation of discolored egg yolks (NRC94; Boushy and Raternik 1987). In addition, dietary free gossypol is reported to possess inhibitor effects on digestive enzymes, and to reduce feed palatability (Waldroup et al 1996). Moreover, gossypol binds with lysine during the processing treatment that requires excessive heat, thus giving rise to the formation of Maillard reaction. This results in the loss or reduction of the protein nutrient's values within the diet (Waldroup et al 1996). However, ferrous sulfate heptahydrate ($FeSO4\ 7H_20$), a highly soluble source of iron (Fe) has shown in a ratio of 1:2 (gossypol/ $FeSO4\ 7H_20$) to bind with free gossypol and inactivate it by forming a strong complex-between Fe and gossypol- in the intestinal tract, thus preventing the pigment from absorption (Waldroup et al., 1996). The literature cites that the dietary contents of free gossypol up to 100 ppm are acceptable in the broiler nutrition (Boushy and Raternik 1987). For a cottonseed meal based–diet with an unkown content in gossypol, an anticipated maximum level of 400-ppm free gossypol in the cottonseed meal should be considered (Waldroup et al 1996). It is desirable to treat the cotton containing diets with the ferrous iron in order to increase the diet's nutrient availability for the bird.

In conclusion, the use of dietary ME to assess NE in the broiler feeds has been of concerns: Yamauchi et al (1996) demonstrated that bird fasting during TME determination is accompanied with gut morphological changes in that both size and height of duodenum and jejunum vilii are reduced. This may reduce nutrient absorption. As a result, using ingredient ME values obtained from birds with impaired absorptive capabilities has been questioned. Moreover, method used to determine the feedstuff tabular metabolizable energy (ME) has raised concerns on the inaccuracy of the ME of different ingredient found in the NRC (1994). Using a bioassay with continuous feeding birds with 0.80% Celite^{TM} as diet ingredient marker, Scott et al (1998) found that the AME values of HRS wheat variety HRS (3,340 to 3,640 kcal / kg) and barley (2,890 to 3,290 kcal / kg) to be significantly higher than the values of the same ingredient varieties found in NRC (1994). The same authors reported that the feed industry in British Columbia has questioned the NRC (1994) values because they do not appear to be accurate when they are used in commercial broiler diets.

HEAT STRESS IN POULTRY

As the bird is constantly producing body heat by metabolism and muscle activity, it must lose some excess heat in order to maintain a constant body temperature (homeotherm). Once the environment temperature rises above 85F, the ability of the bird to lose heat become harder, and as result, poultry have to adjust their behavior in order to increase heat loss and decrease the amount of body heat generated. Indeed, the bird's 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).

Poultry that are heat-stressed are usually recognized by the following behaviors: breathe faster and deeper, spread wings to increase the surface area of the body, drink 2-3 times more water than normal, and eat less than normal (Daghir, 1995). As a result, poultry experience reduced feed intake, altered nutrient absorption, respiratory alkalosis, decreased blood flow to several organs, and changes in endocrine system that negatively affect steroid hormone secretion (Hilman et al., 1985; Etches et al., 1995). These factors have a negative effect on the bird growth rate, reproductive performance and egg quality (Arjona et al., 1987; De Andrade et al., 1977). However, heat dissipation is enhanced by postural adjustments to increase surface area (Baldwin, 1974), vasodilatation of unfeathered extremities, by increasing water intake and urinary volume (Farrell and Swain, 1977; Belay and Teeter, 1993), and by elevating respiration rate from the basal 25 breathes per minutes to as much 250 (Frankel et al; 1962). Respiration rate plays an important role in that a considerable amount of water is evaporated from the mucous membrane of the respiratory tract (Freeman, 1984).

While increased respiratory rate during heat distress has been found critical to maintain constant body temperature, Bottje et al. (1985) reported also that increased respiration rate decreased the partial pressure of carbon dioxide in the blood, leading to a lower bicarbonate concentration and elevated blood pH.

Investigations conducted by Miller and Sunde (1995) and de Andrade *et al* (1976) on heat stressed laying hens have found that compared to the thermoneutral environment, heat stress reduced egg production, egg size, and shell quality while improving feed efficiency. Payne (1966) reported that an increase of 1 degree temperature between 17 ^{o} and 29 ^{o}C resulted in a reduction of 1.6% in feed consumption, which not only lead to lower the bird body weight, but also it might have contributed to the reduction in egg production. Further detrimental effects of heat stress on egg production and shell quality were highlighted in De Andrade *et al*'s study (1977) that showed that both constant heat stress (31 ^{o}C) and cyclic heat stress (26.5-35.6 ^{o}C) significantly reduced hen feed consumption, egg production, egg weight, shell quality (shell thickness, percent true shell, specific gravity), plasma calcium, hematocrit values and serum tyroxine levels when compared to eggs produced at 21°C environment temperature. The authors observed that birds held in cyclic environment temperature had better values in feed efficiency and shell egg quality (except for shell deformation or breaking strength) that those raised under heat stress conditions.

The negative impact of heat distress on the bird water balance was stressed by Teeter and Baley (1993) who found that broilers held in heat stress environment displayed significant ($P<0.05$) increased water consumption and excretion (with urine excretion being independent of water consumption), decreased plasma Na^+ and K^+ ($P<0.05$), and higher plasma Cl^- when compared to the bird held in thermoneutral environment. The authors observed that supplementation of salt in drinking water to the heat stressed bird increased the bird tolerance to the heat distress.

Laying hens are very susceptible to heat stress because of their high metabolic heat production resulting from their high egg production, the presence of feathers that hamper heat dissipation, and the lack of sweat glands (Wolfenson et al., 2001). As homeotherms, laying hens usually suffer heat stress when the sum of heat production and heat gain for the environment becomes greater than the bird's ability to lose it. To cope within a high environmental temperature, the hens rely mainly on their respiratory system for thermolysis, and the heat is lost from their body as either sensible heat (heat that raises the temperature of the surroundings) and insensible heat, or both. Ota et al (1953) observed that the insensible heat becomes the major form of heat dissipation when the environment temperature increases, but vasodilation is also reported to cause an important increase in heat loss from the unfeathered extremities of the bird (Siegel, 1968).

Several approaches aimed at alleviating heat stress in poultry have been developed and applied in poultry rearing facilities and they have resulted in mixed results: roof insulation, orientation of building to maximize natural ventilation, and installation of fans to increase ventilation are utilized in nearly all commercial hen houses in production (Carr and Carter, 1995). However, depending on the seasonal heat severity and the strain of the laying hens, additional management techniques of alleviating heat stress within the hen house are supplied in order to limit the economic losses. Some of the approaches involved are:

THERMAL CONDITIONING (TC): Acute exposure of hens to extreme environmental temperature during the first age of posthatching has resulted in bird with lower body temperature and similar growth performance as the control after the 2 birds were reared in a heat stress environment (Skyles and Fataftah, 1996; Arojana et al., 1987). Basically, this process known also as acclimatization, involves hypothalamic thermoregulatory threshold changes that enable the laying hens, within certain limits, to cope with acute exposure to unexpected heat spells. TC increased the bird growth rate by allowing a full compensation of the body weight after preliminary growth retardation. TC also is reported to induce thermotolerance by modulating heat production through the reduction of plasma T3 concentration during the thermal challenge (Yahav, 1999; 2000). This higher acquired tolerance to heat stress in hen is reported due to a decrease in body temperature, decrease insensible heat loss, decreased oxygen consumption and increased panting rates (Skyles and Fataftah, 1996).

VITAMIN E: Heat stress is reported to stimulate the release of both corticosterone and catecholamine and initiate lipid peroxidation of polyunsaturated fatty acids in cell membrane, generating free radicals (O_2^- and HO^-) that can damage cell membrane, thus giving rise to abnormal membrane integrity in the heat stress exposed hens (Laudicine and Marnett, 1990; Scheideler et al., 2001). As results, the metabolic activity of hepocytes from the heat exposed laying hens is affected, and this dysfunctional synthesis in hepatic cells involved in impaired membrane structure has resulted in a decrease in plasma egg yolk precursor proteins, vitellogenin, and triglyceride (Bollenger-Lee et al., 1998). As an excellent biological scavenger of free radical in cell membrane; vitamin E supplemented to the diet fed in hen exposed to heat stress has significantly improved egg performance (egg mass; egg quality, Haugh units) by improving the egg yolk during the heat tress (Scheideler et al., 1996; 2001).

COOLING SYSTEM: water evaporation is being used on a commercial scale as a means of alleviating hyperthemia in hen exposed heat stress, by cooling hens either directly or indirectly (the latter being based on cooling the microclimate that surrounds the hens). Wolfenson (20001) compared two approaches of direct cooling (dorsal vs ventral) based on a sprinkling system that wets the skin of the hens with large droplets so that the evaporating water cools the bird, and they found that heat stressed hens held under ventral cooling system (cooling hens by wetting the ventral hemisphere of the body that has a less dense plumage than the dorsal region, and several area of apteria) provided significant better values ($P<0.01$) in egg weight, shell index, and lower rectal temperatures than the control (uncooled) or dorsally cooled hens.

FEED RESTRICTION IN POULTRY:

The program of feed restriction is applied in poultry industry for a dual purpose: to limit the bird growth performance in the fast growing broiler in order to offset or prevent the problems associated with metabolic disorders, and in the laying hens or the breeder broiler hens to improve both egg production and egg quality (Yu and al., 1992)

The efficiency of feed restriction on the variables to monitor will depend on the length and level of feed restriction, hen strain, body weight, and bird age or feeding phase at which the program of feed restriction is implemented (Robinson et al., 1992; Yu and al., 1992). Nonetheless, some disagreements still arise among different authors: Robbins et al. (1988) found that birds fed *ad libitum* during either layer transition (24 to 32 weeks of age) or lay phase (24 to 64 weeks of age) produced more eggs and achieved higher peak percentage hen-day production than their counterpart birds fed restricted during that period. This observation was not shared by Robinson et al. (1991) who found that the broiler breeder hens submitted under *ad libitum* feeding plan from 22 to 64 wk displayed significantly lower hen reproductive performance expressed by a shorter length of the prime sequences (24.4 days in the fed restricted hen vs 14.9 days in the *ad libitum* fed hen), and an increased number of long intersequence pauses (more than 11 days) than in the fed restricted hen. Yu et al. (1992) found that birds fed *ad libitum* during rearing or lay displayed significantly higher incidence of erratic ovipositions, defective eggs, and multiple ovulation (soft-shelled, shell-less, or multiple-yolked) that lead to a significant reduction in total settable egg production, when compared with restricted birds during that period. Moreover, the same authors observed a significant reduction in egg production in full fed broiler breeder when compared to the fed restricted one in that the former displayed a higher incidence of ovarian regression (28.4 to 40%) than the latter one (6.3%). Wilson et al. (1991) also found that feed restricted birds lay fewer eggs outside the normal time of oviposition, persist in lay, and lay longer sequences once they were compared to the *ad libitum* fed hens.

LIGHTING AND FEED RESTRICTION ON BIRD HEAT PRODUCTION.

One of the best husbandry strategies used to prevent heat stress in birds consists of reducing heat gain and/or increasing heat loss avenues, and these activities are mainly achieved by manipulating the two potent modifiers of bird heat production: food intake and light (Boshouwers and Nicaise, 1987). Francis et al. (1991) have observed that feed restriction coupled with dark environment significantly reduced bird energy usually allocated to muscular activity and dietary thermogenesis. This was supported by the observation (Millward et al., 1976) that heat stressed bird fed on a high protein diet displayed increased body temperature mainly due to high heat increment resulting from protein concentrations of the diets. Compared to ad libitum in heat stress environment, feed restriction provides better advantages in reducing the energy costs of synthesis and deposition of body material; energy costs of substrate cycling such as protein turnover, and decreasing the thermogenic effect of feeding (heat increment); and all these factors tend to alleviate the bird heat burden (MacLeod, 1993).

In order to grow or yield quality products (i.e., egg), the bird must first have dietary energy that exceeds its maintenance energy requirement (ME_m). Maintenance energy is defined as the amount of metabolizable energy needed to maintain a dynamic equilibrium of protein and fat turnover, to maintain a constant body temperature, and to maintain a locomotor activity. This implies that the total energy retention must be zero although in some cases, such as in growing animal with energy intake around maintenance levels, it is often occurs that the value of fat retention is negative while the protein retention has still a positive value (Chwalibog, 1991). The basal metabolic rate (BMR), defined as the energy needed by the animal to sustain the life process of an animal such as vital cellular activity, respiration and blood circulation, remains the major component of ME_m. BMR is measured when the bird is in the post-absorptive state, emotionally and physically at rest, awake and within bird housed in the thermoneutral environment. As these conditions are seldom achieved with accuracy, because of the varying length of times in birds to reach the post-absorptive state (12-96 h) and the unavoidable and unpredictable experimental conditions that create both physical and emotional distress, fasting heat production (FHP) is usually measured and used in place of BMR.

Investigations conducted on the effects of feed restriction on FHP in birds have provided some conflicting results: Balnave et al. (1979) reported increased FHP in pullets with a similar degree of feed restriction, whereas Fuller and Dunahoo (1962) found lower FHP in fed restricted layer hens. However, Farrell and Johnson (1984) observed no changes in FHP due to feed restriction in birds held in conditions that minimize physical activity. Nonetheless, different authors have demonstrated that factors such as bird body weight (Geers et al., 1978), activity (Van Kampen, 1976), duration of feed removal (Geers et al., 1978), bird strains and age (Leeson and Porter-Smith, 1972) all played a key role in the magnitude of FHP measured. Numerous studies have reported the impact of lighting pattern on heat production and they have linked its impact likely to the activity produced. Lewis et al. (1994) observed that HP in birds held in darkness was 25 –30% lower than that in birds raised in light. Similar result were reported by Li et al. (1991) who found that birds reared in light produced 33% more HP than the birds held in the darkness. These magnitudes of difference in HP were also found in FHP: Damne et al. (1986) found that dark-held birds produced 27% less FHM than the birds held in the light. Overall, regardless of the nutritional status of the bird, lighting system has shown a difference of 22-50% in bird heat production (Lundy et al., 1987). Not only a rational program of lighting pattern applied in bird husbandry resulted in significant improvement of the bird growth performance, feed efficiency, nutrient retention and energy saving (Leeson and Ohtani, 2000; Buyse, 1996), but also it allows a financial gain in saving both lighting energy and feed consumption. Holding into consideration that feed cost covers 60-70 % of the total expenses allocated in broiler business and a decreased feed conversion of 0.17 would save more than 5% in broiler live cost (Emmerson, 1997), a program of rearing bird based on a efficiently elaborated feed restriction (such as skip-a-day of feeding) combined to intermittent lighting may considerably increase the company financial returns.

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CHAPTER III

CHANGES IN GROWTH, PERFORMANCE, FEED CONSUMPTION, ENERGY UTILIZATION AND ESTIMATED CARCASS COMPOSITION OCCURRING IN BROILERS BETWEEN 1994 AND 1999

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ABSTRACT. Regression analysis was used to compare the growth performance, feed consumption, and energy utilization between commercial broilers raised respectively in 1994 and 1999. Viewed at the same age, the 1999 broiler consistently displayed greater BW than the 1994 broiler. At the age of 7 weeks, the 1999 broiler weighed 12.5% more than the 1994 broiler, emphasizing the role of genetic selection on the bird growth performance during the five years that separated the two broilers. In the same context, the 1999 broiler exhibited feed efficiency superior to the 1994 broiler when the two birds were viewed at the same age.

Comparing the two broilers at the equalized body weight, the results showed that the 1994 broiler consumed a greater quantity of both ingredients and nutrient substrates than did the 1999 broiler and such throughout. When the two broilers were compared at an equalized live weight of 2588 g, the 1994 broiler reached it four days after the 1999 broiler, consumed 6.7% more feed than the 1999 broiler, and had a maintenance energy requirement 8.2% higher than that of the 1999 broiler.

The result also indicates that the efficiency of fat and protein retention in the 1999 broiler was of 7.6 and 5.8% higher, respectively than that of the 1994 broiler. Moreover, when the two broilers were compared at the same age (42 d), the energy retained (gain energy) was 10% higher in the 1999 broiler when compared to the 1994 reared broiler.

The study indicates that genetic selection has contributed to improve the broiler efficiency beyond simple improvements in broiler traits.

K*ey words:* broilers, feed consumption, feed ingredients, net energy, efficiency).

INTRODUCTION

Broilers have undergone considerable changes in body weight, feed consumption and carcass composition attributable to genetic selection. Lacy (2000) stated that it took eleven weeks and ten pounds of feed to raise a three pounds broiler five decades ago; whereas a contemporary broiler consumes the same amount of feed to reach the market age of nearly five pounds in less than seven weeks. Chambers et al.(1981) found that at 47 days of age, a broiler raised in 1978 weighed 2.3 times as much as a broiler raised in 1957, whereas at 42 days of age, feed conversion of a broiler raised in 1991 was 30% lower than that of one grown in 1957 (Havenstein et al., 1994a). Factors such as genetic selection, nutrition improvement, husbandry, management and vertical integration within the poultry industry have all contributed to the success of broiler production. Chief among all factors remains genetic selection, which has greatly increased both growth performance and feed consumption, and improved feed efficiency and nutrient retention in modern broiler strains (Pym, 1979; Havenstein et al., 1994a). Different authors have reported that 85 to 90% of the observed increased poultry production is attributed to genetic selection (Sherwood, 1977; Havenstein et al., 1994a). This was highlighted in a study that showed a genetically selected broiler raised in1991 to weigh at 21, 42, 56, and 76 days respectively 3.7, 4.2, 3.9, and 3.5 times larger than a non-selected broiler raised in 1957 (Havenstein et al., 1994a). Further comparisons of growth when the broilers were reared on the same diet (1991 diet) showed also that the modern broiler weighed 3.0, 3.4, 3.1, and 2.9 higher than the non- selected one. Based on the changes occurring in broiler BW over 15 years, Marks (1991) concluded that genetic selection has reduced the broiler market age by nearly one day per year.

Feed conversion has been also improved by genetic selection. The literature showed that at 42 d of age, feed conversion has decreased 47% from 1957 to 1991 (Havenstein et al., 1994b). In another report, however, the feed conversion of broilers during the last 30 years improved by 10% (Lacy, 2000).

From its part, nutrition has also significantly contributed to the increased of broiler production by increasing nutrient availability within the same ingredient, and by improving nutrient retention in the fed birds. This is achieved mainly by using enzymes and growth promoters that, respectively, degrade the anti-nutritive substances present within the diets, and lower the heat increment and energy needed for the bird maintenance. Concomitantly, there is an increase in bird's retained energy for growth (Bedford, 1996). A comparison of the 1991 and 1957 diets for growth performance of selected (1991) and non-selected (1957) strains of broiler at 42 days of age has also shown that the 1991 diet increased the BW of both strains of broilers by 22% and 26% , respectively, when compared to the 1957 diet.

This study was designed to compare the growth performance, feed consumption, ingredient consumption, energy utilization, and estimated carcass composition between broilers raised respectively in 1994 and 1999 in such a way that the time course changes in net energy (1994 vs 1999) might be estimated.

MATERIALS AND METHODS

It was necessary to make two assumptions at the onset of the study. Firstly, the same diets were fed in 1994 and 1999. This assumption extended to chemical and nutrient composition, and included similar feeding periods for both years considered.

Secondly, carcass composition percentages were assumed to not change between 1994 and 1999, and that carcass composition could be appropriately modeled based upon equations of Wiernusz, 1999. Metabolizable energy (MEn in kcal per kg diet) and crude protein (CP; expressed in percentage of the diet) for the different feeding phases were respectively: 3080 kcal/kg and 22.67% for starter (1-21), 3150 kcal/kg and 20% for grower (21-35) and 3240 kcal/kg and 17% for finisher (35-42). The chemical composition of the ingredients that made the diets conformed to published values (Noblet et al., 1993; Church, 1984)

Two growth-feed consumption curves, the first originating in 1994 (a commercial broiler raised in 1994, and the second one in 1999 were used (Tables 2 and 3). Energy value of the carcass was evaluated by using equations established by Wiernusz et al (1999). These equations related live weight, dressing percentage, and dry matter with feed consumption, carcass fat, protein, and energy in broilers from two to six weeks. Consequently, a regression technique was applied to relate the feed consumed by each bird to its respective body weight, and subsequently equations that estimated feed consumed, carcass wet weight and dry weight were established. Simultaneously, equations that predicted protein, fat, ash and energy content for each broiler were developed. Therefore, the two broilers (1994 vs.1999 broiler) at an equalized body weight were compared to describe performance and energetic efficiency. The ingredient chemical composition that constitutes the diet was obtained from Noblet et al (1993). Heat production by the bird (HP) was estimated by subtracting the carcass energy from the metabolizable energy consumed by the bird. Maintenance energy requirement was estimated based on the equation developed in Beker study (1994) that held into account both the bird body weight and energy consumed at a considered age (ME), and ambient temperature.

Statistical analyses

The SAS Program (SAS, 1982) was used for different modeling that served to determine various parameters in investigation. Multiple regression techniques were applied to predict various variables investigated and different computations required within this study.

RESULTS AND DISCUSSION

When the two broilers were compared at the same age, the study shows that the 1999 broiler had greater body weight than the 1994 broiler (Table 4). At 6 wk of age, the 1999 broiler weighed 12.31 % more than the 1994 broiler. By observing the two birds at the same body weight, the result indicates that the 1999 broiler consumed lower quantity of feed than the 1994 broiler (Table 5). In addition, the feed conversion of the 1999 broiler was always lower than that of the 1994 broiler at any equalized body weight considered. The results show that at an equalized body weight of 2500g, the 1994 broiler consumed 6.6% more feed than the 1999 broiler, which in turn, displayed a better feed efficiency than that of the 1994 broiler (Table 5). This result is in agreement with the study of Marks (1979; 1993) that showed an improvement in feed efficiency of 8% from 0 to 8 weeks in the selected broiler when compared to the unselected broilers. In addition, the study indicated that the greatest differences in feed consumption and feed efficiency between the two broilers were observed at early age when broilers weight approximately 250 g: the 1999 broiler consumed 9.4% less feed that the 1994 broiler and had a feed conversion of 9.3% better than the 1994 broiler. This observation supports Marks's finding (1991) that reported large difference in feed efficiency in broilers between the early and late weeks of age. It appears that improved performance during early ages (0-4 weeks) is may be due to the carryover effect from the embryo to the newly hatched chick, to more efficiently utilize certain nutrients, such as amino acids (Lepore et al., 1963).

The same pattern for feed consumption and feed conversion was observed for ingredients and substrates consumed. The 1999 broiler consumed consistently higher levels of ingredients and substrates than the 1994 broiler when the two birds were equal in body weight (Tables 6 and 7). At the equalized body weight of 2500 g, the study showed that total feed, corn, and soybean meal consumed by the 1994 broiler were respectively 6.6, 7.1, and 5.4% higher than in the 1999 broiler. A comparison between the substrate consumption also indicated that at the average market BW (2500 g), the 1994 broiler consumed 7, 7.6, and 5.8% more starch, fat and protein, respectively, than the 1999 broiler. This indicates that the efficiency of deposition of substrates serving as source of energy was higher than that of protein, as it was highlighted in the comparison of the metabolizable energy (ME) consumed by the two birds (Table 8). Again, at the equalized body weight of 2500 g, the 1994 broiler displayed a ME consumption of 6.7% higher than the 1999 broiler In addition, the efficiency of fat accretion in 1999 broiler found to be higher (31%) than protein deposition (Table 9 and 10) supports previous investigations (Broadbent et al., 1981; Perrault and Leeson, 1992) that reported the broiler meatiness has increased less than the improvement of the bird growth rate through selection.

The importance of genetic selection on modern broiler growth rate and energetic efficiency is displayed in a brief summary (Table 11) that compared the energy partition between the two broilers when BW was equalized at 2588 g: the 1999 broiler reached 2588 g four days earlier than the 1994 broiler, consumed 6% less of feed, and has a maintenance energy of 8.2 % lower than the 1994 broiler. In addition, when the two broilers were considered at the same age of 42 d, the 1999 broiler displayed body weight, and energy gain, respectively of 11.6 and 10.0 % higher than the 1994 bird. Similar performances of the modern broiler along the years were recently reported by Chapman et al.(2003). They investigated the growth performance of different broiler production units in the USA from 1997 to 2001 and found a decrease in both calorie conversion and days to raise a 2.27 kg broiler to be 1.4 and 1.5 % per year, respectively. They further reported that there was an average bird final body weight increase of 1.7% per year.

Overall the study demonstrates that considerable improvement in broiler performance have been achieved between the 5 years that separated the years (1994 and 1999) the broilers were raised in, when the two broilers were considered at any equalized body weight. The reduction in either market age or feed consumption of the 1999 broiler compared to its counterpart 1994 broiler will result in a significant increased financial gain in the 1999 broiler 's operated business when compared to the 1994 broiler's one.

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Table 1. Composition of the diets fed to the broilers at their respective age.

	Rations (%)		
Ingredients	Starter	Grower	Finisher
Ground Corn	61.0	65.4	70.8
Soybean meal (44%CP)	29.0	27.0	21.3
Fat	6.8	5.4	4.3
Dicalcium phosphate	1.73	1.20	1.50
Limestone	1.00	1.50	4.20
Salt	0.40	0.30	0.40
Vitamin mix[1]	0.30	0.30	0.30
DL-Methionine, 99%	0.11	0.20	0.20
Trace mineral mix[2]	0.05	0.10	0.10
Calculated Analysis			
ME (kcal/kg)	3080	3157	3232
Crude protein (%)	22.67	20.2	17.33
Calcium (%)	1.0	0.9	0.8
Phosphorus (%)	0.72	0.68	0.60

[1] The Vitamin mix contained per kilogram: vitamin A, 3,968,280 IU.; vitamin D_3, 1,102,300 IU; .vitamin E, 13,228 IU; vitamin B12, 7.9 mg; riboflavin, 2,646 mg; niacin, 17,637 mg; d-pentatonic acid, 4,409 mg; choline, 200,178 mg; menadione, 728 mg; folic acid, 441 mg; pyridoxine, 1,587 mg; thiamin, 794 mg; d-biotin, 44 mg

[2] Mix contained manganese, 12.0%; zinc, 10.0%; Iron, 7.5%; copper, 1.0%; iodine, .25%; calcium, 13.5%

Table 2. Body weight, cumulative feed consumption and feed conversion ratio (FCR) per age of the commercial broiler reared in 1994 (broiler94).

Age (week)	Weight (g)	Cumulative Feed Consumption (g)	FCR[1] (g/g)
1	152	135	0.88816
2	376	425	1.13032
3	686	912	1.32945
4	1085	1616	1.48940
5	1576	2576	1.63452
6	2088	3717	1.78017
7	2590	4998	1.92976
8	3077	6430	2.08970
9	3551	8007	2.25486

[1]=Feed conversion ratio

Table 3. Body weight, cumulative feed consumption and feed conversion ratio (FCR) per age of the commercial broiler reared in 1999 (broiler99)

Age (day)	Weight (g)	FCR (g/g)	Feed Consumption (g)
1	58.97	0.21	12.38
3	95.25	0.55	52.39
5	140.61	0.76	106.87
7	195.04	0.90	175.54
9	258.55	0.99	255.96
11	331.12	1.07	354.30
13	417.30	1.14	475.73
15	508.02	1.20	609.63
17	612.35	1.25	765.44
19	721.21	1.30	937.58
21	843.68	1.34	1130.53
23	970.69	1.38	1339.55
25	1102.23	1.42	1565.17
27	1238.31	1.47	1820.31
29	1378.92	1.50	2068.38
31	1524.07	1.54	2347.07
33	1669.22	1.58	2637.37
35	1814.37	1.62	2939.28
37	1964.05	1.66	3260.33
39	2118.28	1.70	3601.07
41	2267.96	1.74	3946.25
43	2422.18	1.78	4311.49
45	2580.94	1.82	4697.31
47	2739.70	1.86	5095.84
49	2898.46	1.90	5507.84
51	3057.21	1.94	5930.99

Table 4. Body weight, and improvement of BW between the 1994 and 1999 broilers at the same age

	Broiler94	Broiler99	
Age	live weight	live weight	Improvement[1]
(week)	(g)	(g)	(%)
1	152	195.04	28.32
2	376	508.02	35.11
3	686	843.68	22.99
4	1085	1310.88	20.82
5	1576	1814.37	15.13
6	2088	2345	12.31
7	2590	2898.46	11.91

[1]=[(99 broiler live weight-94 broiler live weight) /94 broiler live weight] x 100

Table 5. Feed intake and feed conversion ratio (FCR) of the 1994 and 1999 broiler at equalized body weight

	Feed Intake			FCR		
Liveweight	1994	1999	Improvement[1]	1994	1999	Improvemen[2]
(g)	(g)	(g)	(%)	(g/g)	(g/g)	(%)
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

[1]=[(94 broiler feed intake-99 broiler feed intake) /99 broiler feed intake]x100.

[2]=[(94broiler feed conversion-99 broiler feed conversion) /99 broiler feed conversion]x100.

Table 6. Ingredient consumption by the 2 commercial broilers (94 and 99) at the equalized body weight

Live weight	94Corn consumed	94Soybean consumed	94Fat consumed	94Propak consumed	99Corn consumed	99Soybean consumed	99Fat consumed	99Propak consumed
(g)	(g)	(g)	(g)	(g)	(g)	(g)	(g)	(g)
250	167.07	79.04	5.18	13.08	152.74	72.26	4.73	11.96
500	379.52	179.55	11.76	29.72	367.72	173.96	11.40	28.79
1000	896.96	398.82	32.31	56.69	872.93	389.26	31.24	55.74
1500	1527.91	649.65	60.29	80.81	1470.01	626.63	57.22	78.60
2000	2260.35	940.84	92.77	108.81	2146.17	895.44	87.70	104.44
2500	3152.15	1222.01	137.25	132.12	2943.33	1159.19	126.63	127.10
3000	4164.83	1526.67	188.74	156.43	3846.53	1430.91	172.56	148.79
3500	5287.38	1864.39	245.82	183.39	4835.33	1728.39	222.83	172.53

Table 7. Substrate consumption by the 2 broilers at equalized body weight

	Starch			Fat			Protein		
Liveweight (g)	1994 (g)	1999 (g)	Improvement[1] %	1994 (g)	1999 (g)	Improvement[2] %	19944 (g)	1999 (g)	Improvement[3] %
250	121	110	10	15	14	9.3	71	65	9.2
500	274	265	3.4	35	34	2.9	162	157	3.2
1000	645	628	2.7	85	82	3.7	358	350	2.3
1500	1097	1055	4.0	148	141	5.0	583	563	3.6
2000	1621	1540	5.3	220	209	5.3	845	804	5.1
2500	2254	2106	7.0	312	290	7.6	1114	1053	5.7
3000	2972	2747	8.2	415	382	8.6	1410	1317	7.1
3500	3768	3447	9.3	530	484	9.5	1738	1606	8.2

[1] =Efficiency of starch consumption between the 2 broilers
=(broiler94 starch consumed- broiler99 starch consumed)/broiler99 starch consumed

[2] =Efficiency of fat consumption between the 2 broilers
=(broiler94 fat consumed- Cob99 fat consumed)/Broiler99 fat consumed

[3] =Efficiency of protein consumption between the 2 broilers
=(broiler94 protein consumed- Cob99 protein consumed)/Broiler99 fat consumed

Table 8. Comparison of metabolizable energy (ME), carcass energy, and heat production (HP) between the 94 and 99 reared broilers.

	ME			Carcass	HP	
Liveweight (g)	94 kcal/bird	99 kcal/bird	Improvement[1] (%)	94 = b99 kcal/bird	94 kcal/bird	99 kcal/bird
250	839	798	9.38	198	642	570
500	1907	1847	3.21	521	1386	1327
1000	4440	4324	2.68	1227	3212	3096
1500	7485	7206	3.88	2025	5461	5181
2000	11021	10470	5.26	2921	8101	7550
2500	15128	14175	6.73	3925	11203	10250
3000	19753	18299	7.94	5051	14701	13248
3500	24879	22815	9.05	6312	18567	16502

[1] =[(94 broiler ME consumed-99 broiler ME consumed) /99 broiler ME consumed]x100.

Table 9. Fat consumption and retention between the 2 broilers

	94 broiler			99 broiler			
Live weight (g)	Fat consumed (g)	Carcass Fat (g)	Fat retention (%)	Fat consumed (g)	Carcass Fat (g)	Fat retention (%)	Improvement[1] (%)
250	15	3.33	21.77	14	21.77	23.81	9.37
500	35	25.91	74.03	34	25.91	76.21	2.94
1000	85	73.22	86.14	82	73.22	89.29	3.66
1500	148	123.47	83.43	141	123.47	87.57	4.96
2000	220	176.72	80.33	209	176.72	84.56	5.27
2500	312	233.06	74.70	290	233.06	80.37	7.59
3000	415	292.58	70.50	382	292.58	76.59	8.64
3500	530	355.36	67.05	484	355.36	73.42	9.50

[1]=[(99 broiler fat retention-94 broiler fat retention) /94 broiler fat retention]x100.

Table 10. Protein consumption and retention between the 2 broilers

	94 broiler			99 broiler			
Live weight	Protein consumed	Carcass protein	Protein retention	Protein consumed	Carcass protein	Protein retention	Improvement[1]
(g)	(g)	(g)	(%)	(g)	(g)	(%)	(%)
250	71	22.78	32.03	65	22.78	35.04	9.38
500	161	51.87	32.22	156	51.87	33.25	3.20
1000	358	113.48	31.70	350	113.48	32.42	2.27
1500	583	179.49	30.79	563	179.49	31.88	3.54
2000	845	251.22	29.73	804	251.22	31.25	5.11
2500	1114	327.86	29.43	1053	327.86	31.14	5.81
3000	1410	410.02	29.08	1317	410.02	31.13	7.05
3500	1738	497.95	28.65	1606	497.95	31.01	8.23

[1] =[(99 broiler protein retention-94 broiler protein retention) /94 broiler protein retention]x100

Table 11. Partitioning of energy savings between the 2 broilers (94 vs 99 broilers)

	Unit	94 broiler	99 broiler	Difference
Live Weight (g)	(g)	2588	2588	0
Days	(d)	49	45	4 days
ME Consumed	(kcal/b)	15994	15114	880
MECons/BWT	(kcal/b)	6.18	5.84	0.34
Maintenance E	(kcal/b)	5672	5244	428
Maint E/ME Cons	%	35.5	34.7	
Energy for Gain (RE)	(kcal/b)	10322	9870	
RE Efficiency	%	64.5	65.3	
Carcass energy	(kcal/b)	4275	4275	
Carc En+2% yield	(kcal/b)		4381	
Carc En/En Gain	%	0.414	0.433	187
Carc En if +2% Yield	%		0.444	296
Calorie save	(kcal/bird)	880 (Consumption):		
Repartition:			* 428 Maintenance) * 296 (Gain) * 156 (Unaccounted, Activity??)	

CHAPTER IV

THE INFLUENCE OF ISOCALORIC RATION COMPOSITION IN COMPLEX DIET MIXTURE ON BROILER PERFORMANCE AND ENERGETIC EFFICIENCY

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ABSTRACT: Growth performance and energetic efficiency were compared among birds fed isocaloric and isonitrogenous rations made of several ingredients in complex diets. Twelve diets containing seven ingredients were formulated for each growing phase of the bird (14, 28 and 42 days) and fed to the broilers from 1 up to 42 days. The chemical composition of the seven experimental ingredients was determined for 8 analyts. Consumed dietary metabolizable energy (ME), net energy (NE) and performance of the fed birds were compared ingredient difference.

The results indicate that there were no dietary differences in feed intake, weight gain, fed heat production, fasted heat production, basal metabolic rate, and heat production per kg metabolic body weight, weight gain per body weight, retained energy, and net energy over a determined period. However, age factor showed significant effect on feed intake ($P<0.0001$), metabolizable energy consumed ($P<0.0001$), fasted heat production ($P<0.009$), net energy ($P<0.05$), efficiency of net energy ($P<0.07$), heat production per kg metabolic body weight ($P<0.0001$) and weight gain per body weight ($P<0.0001$) among the fed birds.

The study suggests that a variety of ingredients can efficiently be used to formulate the broiler diet, provided that the respective diets have nearly quantitative and qualitative equal amount of nutrients regardless of the source of origin.

Key Words: Broilers, ingredient levels, diets, growth performance, net energy

INTRODUCTION

A wide variety of the ingredients are used to make broiler diets wherever poultry are raised. These ingredients have different chemical compositions that can efficiently complement each other in making a balanced and complete nutritional diet for the birds. When poultry growers rely on a unique ingredient as a source of either protein or energy to feed their birds, they can experience problems in feed supply due to some factors (abiotic or biotic) beyond their control that can deprive them from getting enough feed to raise their birds. Considering that the gain remains the alpha and omega in any economic operation, we deem it worthwhile to investigate alternatives to the major reliable ingredients that make up bird diets, in order to avert any eventual feed shortage. Such a goal would be fulfilled by investigating the effect of a mixture of several ingredients that constitute different diets with equal metabolizable energy (ME), on the broiler growth performance and efficiency of energy utilization.

Previous studies have demonstrated that birds raised on equivalent supplemental ME quanta derived from starch, protein or fat exhibited significant differences in energy gain (Mittelstaedt et al., 1987). Equal amounts of protein gain were observed with differing fat retention reported for treatments. The study highlighted the impact of nutrient substrates on energetic efficiency and showed that ME was unlikely to accurately predict the net energy (NE). Indeed, ME of the diet serves to indicate only how much of the energy is potentially available for the bird, but it doesn't show how of much the available energy is partitioned into production and maintenance. Similarly, birds fed six feeds containing equivalent amounts of vegetative fat, protein, and starch concentrations have displayed no differences in AME, but significant differences in energy retention and feed conversion ratio among the birds were observed (Collier et al., 1996). The above studies suggest that birds fed isocaloric diets may not always have similar performance or net energy gain. This was also reported by MacLeod et al. (1998) who found that diets formulated on the basis of ME and NE requirements (NE was set equal to 0.75 ME on the basis of a previous study) failed to provide similar growth performance to the birds (0-21 d old birds). The results showed that birds fed diets formulated on the basis of NE had a significant higher mean body weight ($P<0.001$), improved feed conversion ($P<0.001$), and cumulative intake of both TME and NE significantly higher ($P<0.01$) than the birds fed ME formulated diets. This implies that heat increment or energy associated with absorption, excretion, and secretion likely differed among the isocaloric diets, and as a result, the retained energy differed among the isocaloric diets.

Further differences in energy retention from broilers fed on equal dietary ME were observed by Muramatsu et al.(1994) who fed isocaloric diets to the conventional and germ-free chickens (CV and GF). At the end of the experiment, the authors observed that while the CV birds had an increased heat production (due to their increased microbial fermentation), they displayed a reduction of 16% in energy retention than the GF chickens. The study showed that broiler gut microflora impacted energy retention and again highlighted cases where the bird energy retained is not accurately correlated to its metabolizable energy.

Pirgozliev et al. (2001) have shown that broiler chickens fed 12 isoenergetic diets made of 6 different wheat cultivars with both nearly similar proximate nutrient composition and equal AME displayed significant difference in carcass energy retention. The difference was likely due to the increased digesta viscosity observed among the different diets. Given that increased digesta viscosity gives rise to a proliferation of microflora in the small intestine, that leading to increased nutrients available for fermentation in the lumen of the digestive tract (Annison and Choct., 1990; Choct and Annison., 1992; Bradford; 1996), it is likely that the heat increment of the wheat cultivar was increased in diets with higher digesta viscosity to the detriment of MEn available for growth and carcass energy retention.

The investigation of Nitsan et al. (1997) dealing with increasing broiler diets with oil (fat) above the required dietary level has highlighted the impact of fat density on the energy retention. The authors observed a significant increase in broiler weight gain and net energy deposition that was not correlated to the increase in the ME in broilers fed the diet supplemented with extra oils, when compared to the birds raised on the normal diet (Nitsan et al., 1997). This shows the significant effect of dietary fat on the broiler net energy or tissue deposition that the dietary ME can neither detect nor predict. Further investigation on the nature of dietary fat has revealed its impact on both energy retention and its partitioning. Isocaloric diets (supplemented with either unsaturated vegetable oil or beef tallow as the major source of fat) fed to broilers resulted in significantly higher body fat retention and lower protein accretion in the birds fed diets supplemented with saturated fatty acids when compared to broilers fed diets with unsaturated fatty acids (Sanz et al., 2000). However, no differences in weight gain, feed intake, or feed to gain ratio were observed among the broilers.

Exogenous enzymes in broiler diets supplemented with either saturated or non-saturated fatty acids have provided significantly different effects in broiler diets. Polyunsaturated fatty acid in a rye diet treated with xylanase significantly increased the metabolizable energy (AME/GE) more than the xylanase treated diets fed with supplemented saturated fatty acids (Danicke et al., 1999). On the other hand, the inverse was true for energetic efficiency (NE/AME). Saturated fatty acids were more efficient in energy retention than the unsaturated fatty acids in the isocaloric diets supplemented with the enzymes. All this highlights the impact of the chemical composition of the ingredients on the performance of the fed bird. Indeed, the various interactions occurring among the chemical composition of different ingredients that constitute the bird diets may result in unpredicted variations in bird performance and energy partitioning.

The study reported herein was designed to compare the growth performance and energetic efficiency from broilers fed both isocaloric and isonitrogenous diets made of several ingredients in complex diets. In order to optimize the probability of getting similar performance, care was taken to provide similar levels of protein, Ca, P, total sulfur amino acids, and major essentials amino acids such as lysine, and threonine to all the isocaloric diets.

MATERIALS AND METHODS

Proximate analysis of seven principal ingredients (corn, wheat, milo, barley, soybean, cottonseed, and peanut meal) used in the study was performed (AOAC, 1984), and these ingredients (Table 1) were used in various ratios and mixtures, to formulate twelve diets for each growing phase of the birds (starter, grower and finisher), see Table 2. To improve the efficiency of the ingredient nutrients fed to the birds, diets containing wheat and barley were supplemented with their respective enzyme Wheatase (0.06 %) and Barlex (0.1%), whereas diets that contained cottonseed meal were supplied with ferrous sulfate heptahydrate (0.04%). All the diets for the same growing phase were both isoenergetic and isonitrogenous. In addition, they contained equal amounts of major nutrients such as calcium, phosphorus, total sulfur amino acids, lysine, and threonine.

The corrected metabolizable energy of each diet (MEn) was formulated based on the percentage of each ingredient in the diet composition, and the respective ingredient's established MEn value (Janssen *et al.*, 1979). The respective isocaloric and isonitrogenous diets were formulated using the Agri-Data Systems Inc. Program; a Visual Least Cost Feed Formulation Program. Each diet contained from two to five ingredients, and all diets met the NRC (1994) requirements in nutrients and energy needed for the growing birds. Laboratory analyses were performed to determine the gross energy of each ingredient through bomb calorimetry, and in conjunction with the proximate analysis of the ingredients, the gross energy of each diet was calculated.

BIRD HANDLING

Five groups of commercial 0-day old male broiler chicks Broiler-500 were obtained at 14 day of intervals. The chicks were reared on in floor pens with wood shavings litter to 14, 28, and 42 days. There were 12 treatments (diets) for each group and each growing phase of the bird, and the birds were provided at libitum access to feed and water. At 14, 28, and 42 days of age, 1-2 birds from each treatment were randomly selected from the pens and transferred to the open circuit respiratory chambers previously described by Belay and Teeter (1993) where they were fed their respective diets as follows: the birds were first fasted for twelve hours prior to being introduced in the metabolic chambers for adaptation for 14h. During this adaptation period, the birds were fed their respective diet. Water was provided ad libitum during the whole experiment. At the end of the adaptation period, the birds were weighed and then fasted for another 12h. Following the fasting period, the birds were fed their respective diets during 72h. Following the feeding period, the birds were fasted again for 36 hours that were followed by 4 hours of fasting in the dark. The birds were then weighed, sacrificed by CO_2 asphyxia, and stored in a freezer for further analysis.

During the feeding period, feed consumed by the birds was recorded. At the end of both the feeding experiment and fasting in dark, the birds were weighed, and the excreta was collected and processed to further determine the dietary MEn consumed by the bird. Gases exchanges between the birds and the environment during the feeding and fasting phases was recorded and processed for further energetic estimation.

The data were analyzed using the SAS program to assess any impact of the age and (or) the diets on the bird performance. In addition, the bird's body weight, along with its age (days), and feed consumed per age were evaluated, and daily feed intake as well as daily weight gained was evaluated.

Statistical analyses.

Data for all response variables were subjected to analysis of variance using the General Linear Models procedure of SAS (SAS, 1985). When a significant F statistic was noted by ANOVA, treatment means were compared using least square analysis of variance (Steel and Torrie, 1960)

RESULTS AND DISCUSSION.

The chemical composition of the ingredients analyzed (Table 1) provided similar values as those of the same ingredients already reported in the literature (Noblet et al., 1993; Church, D.C; 1984). The composition of the respective diets and their nutrient content is given in the Tables 2 to 7. The present study shows that there were no significant differences in bird feed intake, feed efficiency, weight gain, and weight gain per body weight among birds of similar ages over a period considered (Table 8). This indicates that the different isocaloric diets provided similar growth and feed consumption, regardless of the source of nutrients. The significant difference observed in final bird body weight was due to the bird initial body weight that was significantly different prior to starting the feeding experiment.

The observed similarities in growth performance among the birds fed isocaloric diets should be expected as the diets were isocaloric and contained the same levels of crude protein, and nearly equal amounts of all major nutrients. In addition, they were also supplemented with specific enzymes that served to degrade the anti-nutritive substances present in diets; thus increasing the nutrient availability to the birds. Similar growth of birds fed on isocaloric diets were also reported by Blair et al (1996), who found that broilers fed isocaloric diets made of either white sorghum or sorghum with tannin content of either 1.3 or 2 % (catechin equivalent basis) had similar body weight and feed conversion as broiler raised on an a corn-based diet having equal energy as the aforementioned diets. This has led the same authors (Blair et al., 1996) to suggest that sorghum may efficiently substitute for corn in broiler nutrition with no deleterious effects on the bird performance. However, they further reported that brown sorghum, such as Serena (with a tannin level up to 3.7%) resulted in lower performance to the fed broilers. The diet depressed broiler growth, lowered egg production, and increased egg mottling in laying hens (Blair et al., 1996). Similarly, Sanz et al. (2000) observed differences in both protein and fat retention among broilers fed isocaloric diets that differed only in fat source, but the authors reported similar bird weights and feed efficiency.

The present study didn't show any significant differences among the birds of same age in fed heat production per kg of diet, fasted heat production per kg of diet, BMR per kg of diet, retained energy per kg of diet, efficiency of retained energy (REEFF), net energy per kg diet, efficiency of net energy per kg of diet (NEEFF), heat production per kg of metabolic body weight (HPKMBW), as well as bird weight gain per bird body weight (WTGNPBW), see Table 9 to 11.

The age affected both feed consumption ($P < 0.001$) and bird weight gain ($P < 0.0001$) among the birds fed on different isocaloric diets (Table 8). However, there were no significant differences in weight gain between the 4 and 6 wk-old birds, even though the latter bird consumed significantly higher quantities of feed than the 4 wk-old broilers (Table 8). This likely implies that the 4 week olds birds are in a growth phase where they utilized feed more efficiently for the development of muscle tissue and the other organs to reach mature BW.

While there were no observed dietary differences in fed heat production, retained energy, or BMR among the birds of different ages, differences were found in net energy ($P < 0.05$), efficiency of net energy ($P < 0.05$) and fasting heat production ($P < 0.0001$), as it is shown in Tables 10 and 11. The differences found in net energy are difficult to explain from a nutritional standpoint, given that both retained energy and BMR of the respective birds didn't display significant differences. Nonetheless, previous studies have demonstrated that factors such as intestinal microflora, levels and nature of fatty acid present within the diets, substrate chemical composition, interaction among the dietary chemical composition, and other unknown factors caused substantial changes in bird performance or net energy deposition that dietary ME can't accurately assess or predict (Meulen et al., 1997; Muramatsu et al., 1996; Collier et al., 1996; Pirgozliev and Rose, 1999; Noblet et al., 1993; Sanz et al., 2000). These factors may also be involved in the present study that finds differences in net energy among the birds of the same age fed different diets. It is worth noting that in order to optimize the efficiency of nutrient utilization and to avoid any differences than might appear within the agemate broiler performances, all the diets were formulated to be isocaloric and isoproteinous for a certain age of the bird, and also they contained equal amount of calcium, total phosphorus, lysine, total sulfur amino acid, calcium, and threonine. Moreover, they contained both synthetic amino acids, and Propak (bone and meat product with high level in protein) as a source of supplemental protein with high amino acid digestibility.

The result indicates that the different isocaloric diets had no significant effects on the broiler weight, heat production per day, and metabolizable energy consumed when expressed per unity of body weight, while all these variables were significantly different at the bird age. The youngest birds always had greater values for the aforementioned traits than did the older birds (Table 10). This was likely due to the greater metabolic activity at younger ages.

The present study shows that the efficiency of both energy retention (REEFF) and net energy (NEEFF) keeps improving over the years of rearing birds, when compared to other data given in the literature (Table 12 and 13). This observation likely implies that genetic selection, nutritional improvements, and husbandry management applied in the poultry business have all brought beneficial effects to broiler growth performance throughout the years. Farrell (1980) reported a REEFF varying between 0.31-0.38% in 1980; then it increased to 0.38-0.41 % 10 years later (Whitehead, 1990) to reach 0.49-0.56% in 2001 (Pirgozliev et al., 2001). In the present study, the REEFF varied between 0.48-0.62%. Farrel et al. (1980) reported two decades ago that the efficiency of net energy in chickens to be 0.50%, and a value of 0.86% has been recently reported within cockerels (Mc Nab, 2000). The present study reports an efficiency of net energy that varied between from 0.72 and 0.82%. This suggests that the efficiency of nutrient utilization for the bird growth purposes has considerably increased over the years of poultry breeding, and this was likely due to a substantial decrease in either heat increment or maintenance energy requirement for the bird, or both.

In conclusion, the study demonstrates that various ingredients in diets mixture can clearly positively contribute to the bird growth performance and energetic efficiency in making efficient diets, provided that the diets meet the bird requirement for growth at the specific age, and appropriate adjustment needed for each ingredient are made

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Table 1. Chemical Composition (%) and Gross Energy (kcal/kg) of the Ingredients[1]

Ingredient	DM	Starch	GE	CP	EE	CF	Ash
Corn	87.3	62.9	3980	8.8	2.8	2.84	2.07
Wheat	88	62.3	3961	14.3	1.1	2.31	1.99
Milo	87.7	62.3	3963	9.8	2.4	6.09	2.95
Barley	88	54.1	3948	11.2	1.9	6.81	2.47
SBM	90.6	5.7	4335	50.2	1.4	15.51	6.61
CSM	89.6	4.8	4330	41.2	2.2	19.66	4.57
PNM	92.4	7.2	4675	39.9	9.8	12.72	4.75

[1] Dry matter (DM), gross energy (GE), crude protein (CP), EE (ether extract), CF (crude fiber), Cottonseed meal (CSM), Peanut meal (PNM),

Table 2. Percent Composition of Starter Diet

Ingredient/Diets	1	2	3	4	5	6	7	8	9	10	11	12
Corn	50.71	25.91	14.41	58.7	-	53.8	-	-	-	18.5	55.9	-
Wheat	-	-	47.6	-	65	-	-	36.5	-	-	-	-
Barley	-	32.2	-	-	-	-	-	-	18	39.7	-	-
Milo	-	-	-	-	-	-	58.2	26.21	41.2	-	-	55.60
Soybean	4.75	21	15.5	28.98	19.56	8.92	28.4	22.85	25.82	26.48	15.8	14.4
Cottonmeal	30	-	7	-	-	-	-	-	-	-	-	15
Peanutmeal	-	5	-	-	-	24	-	-	-	-	15	-
Fat	5.35	6.03	5.95	4.1	6.57	3.88	5.44	5.85	5.94	6.93	3.82	5.42
Propak	4.78	6.7	5.75	4.73	5.12	5.42	4.12	5.04	5.80	5.30	5.75	5.65
WheatEase	-	-	0.029	-	0.039	-	-	0.022	-	-	-	-
Barlex	-	0.032	-	-	-	-	-	-	0.018	0.04	-	-
$FeSO_4(7H_2O)$	0.024	-	0.0056	-	-	-	-	-	-	-	-	0.012

Table 3. Percent in Nutrient Composition of Starter Diet

MEn	**kcal/kg)**	**3074**	**3088**	**3069**	**3076**	**3080**	**3087**	**3085**	**3088**	**3087**	**3099**	**3083**	**3080**
CP	%	22.9	22.9	22.9	22.9	22.9	22.9	22.9	22.9	22.9	22.9	22.9	22.9
Lys	%	1.21	1.21	1.21	1.21	1.21	1.21	1.21	1.21	1.21	1.21	1.21	1.21
TSSA	%	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.99
Thr	%	0.89	0.87	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.88	0.87
Starch	%	33.6	35	38.4	38.5	39.5	36.1	37.9	39.1	36.7	34.4	37.1	36.2
Fat	%	7.25	8.79	7.66	6.50	7.93	8.29	7.53	7.57	8.06	8.95	7.56	7.72
CF	%	5.71	3.91	3.50	2.16	2.89	5.36	2.77	2.83	3.18	3.56	4.14	4.47
ADF	%	8.06	6.69	5.29	6.16	4.55	6.10	7.95	5.98	7.74	7.33	5.95	8.57
ADL	%	2.08	1.63	1.68	1.52	1.62	1.54	1.57	1.57	1.58	1.75	1.50	1.75
NDF	%	15.2	14.0	12.6	12.2	12.0	13.4	12.1	12.5	13.8	14.5	12.5	14.5

CP=crude protein; Lys=lysine; TSSA=total sulfur amino-acid; Thr=threonine; CF = crude fiber;

ADF = acid detergent fiber, ADL= Acid detergent lignin; NDF = neutral detergent fiber

Table 4. Percent Composition of Grower Diet

Ingredient/Diets	1	2	3	4	5	6	7	8	9	10	11	12
Corn	61.3	31.6	16.4	65.55	-	60.44	-	-	-	42.8	62.6	-
Wheat	-	-	53.21	-	71.99	-	-	18	-	-	-	-
Barley	-	33.22	-	-	-	-	-	-	26.55	21	-	-
Milo	-	-	-	-	-	-	66.17	48.26	39.16	-	-	62.79
Soybean	4.935	14.81	8.02	22.72	13.19	7	20.42	20.88	19.22	23	15.16	7.72
Cottonmeal	20	-	7	-	-	-	-	-	-	-	-	15
Peanutmeal	-	5	-	-	-	20	-	-	-	-	10.1	-
Fat	4.58	6.22	6.20	4.17	7.10	4.34	5.27	6.15	6.7	6	4.4	5.55
Propak	5.76	6.36	5.8	4.61	4.2	4.39	5.03	3.19	5.5	4.33	4.2	5.47
WheatEase	-	-	0.032	-	0.043	-	-	0.011	-	-	-	-
Barlex	-	0.032	-	-	-	-	-	-	0.027	0.021	-	-
$FeSO_4(7H_2O)$	0.0016	-	0.0056	-	-	-	-	-	-	-	-	0.012

Table 5. Percent in Nutrient Composition of Grower Diet

MEn	Kcal/kg	3154	3168	3148	3155	3160	3167	3165	3168	3167	3180	3163	3160
CP	%	20.2	20.2	20.2	20.2	20.2	20.2	20.2	20.2	20.2	20.2	20.2	20.2
Lys	%	1.10	1.09	1.10	1.10	1.09	1.09	1.10	1.09	1.09	1.08	1.09	1.10
TSSA	%	0.80	0.80	0.79	0.79	0.80	0.79	0.80	0.80	0.79	0.79	0.80	0.79
Thr	%	0.81	0.81	0.81	0.81	0.81	0.81	0.82	0.81	0.82	0.82	0.82	0.82
Starch	%	39.8	39	42.6	41.5	43.3	39.9	42.4	41.9	39.8	39.6	40.2	40.3
Fat	%	7.78	8.10	7.98	6.69	8.40	8.48	7.53	8.04	8.84	8.25	7.67	7.87
CF	%	4.37	3.84	3.43	2.04	2.88	4.73	2.69	2.79	3.35	2.82	3.41	4.42
ADF	%	6.43	6.09	4.29	5.38	3.71	5.34	7.19	6.59	7.17	6.21	541	7.96
ADL	%	1.52	1.35	1.38	1.23	1.38	1.29	1.20	1.35	1.35	1.43	1.28	1.45
NDF	%	13.8	13.9	12.4	12.0	11.8	12.6	13.0	12.9	14.1	13.3	12.3	14.4

CP=crude protein; Lys=lysine; TSSA=total sulfur amino-acid; Thr=threonine; CF = crude fiber;

ADF = acid detergent fiber, ADL= Acid detergent lignin; NDF = neutral detergent fiber

Table 6. Percent Composition of Finisher Diet

Ingredient/Diet	1	2	3	4	5	6	7	8	9	10	11	12
Corn	67.35	37.89	21.8	71.46	-	67.53	-	-	-	41	68.69	-
Wheat	-	-	51.3	-	79.84	-	-	37.95	-	-	-	-
Barley	-	33.4	-	-	-	-	-	-	22.0	31.00	-	-
Milo	-	-	-	-	-	-	72.15	38.82	51.08	-	-	69.62
Soybean	-	8.5	3.6	17.1	5.33	2.90	15	9.2	12.4	13.9	10.05	4.18
Cottonmeal	19.08	-	7	-	-	-	-	-	-	-	-	12.23
Peanutmeal	-	5	-	-	-	17.42	-	-	-	-	10	-
Fat	5.02	6.44	6.6	4.58	7.42	4.5	5.82	6.29	6.5	6.47	4.73	6.01
Propak	5.2	6.18	4.45	4	4.3	4.1	4.07	5	5.6	5.3	3.2	4.8
WheatEase	-	-	0.031	-	0.043	-	-	0.023	-	-	-	-
Barlex	-	0.033	-	-	-	-	-	-	0.022	0.031	-	-
$FeSO_4(7H_2O)$	0.0015	-	0.0006	-	-	-	-	-	-	-	-	0.098

Table 7. Percent in Nutrient Composition of Finisher Diet.

MEn	kcal/kg	3233	3249	3228	3235	3241	3247	3245	3248	3247	3261	3244	3241
CP	%	17.5	17.5	17.5	17.5	17.5	17.5	17.5	17.5	17.5	17.5	17.5	17.5
Lys	%	0.94	0.94	0.94	0.93	0.94	0.94	0.94	0.94	0.94	0.94	0.93	0.94
TSSA	%	0.66	0.66	0.66	0.66	0.66	0.66	0.66	0.66	0.66	0.66	0.66	0.66
Thr	%	0.76	0.75	0.75	0.74	0.74	0.75	0.75	0.75	0.75	0.5	0.75	0.75
Starch	%	43.2	42.8	45.8	45.9	47.5	43.9	45.8	47.1	44.4	43.3	44.5	44.3
Fat	%	7.57	9.23	7.83	7.14	8.75	8.46	8.08	8.32	8.94	8.82	8.03	8.34
CF	%	4.15	3.72	3.34	1.94	2.84	4.27	2.66	2.73	3.18	3.00	3.31	4.05
ADF	%	5.66	5.30	3.79	4.68	2.67	4.58	6.72	4.66	6.53	5.43	4.78	7.29
ADL	%	1.24	1.06	1.16	0.97	1.08	1.00	0.96	0.96	1.00	1.09	1.04	1.13
NDF	%	13.5	13.7	12.3	11.8	11.6	12.3	13.0	12.3	13.8	13.6	12.2	14.1

CP=crude protein; Lys=lysine; TSSA=total sulfur amino-acid; Thr=threonine; CF = crude fiber;

ADF = acid detergent fiber, ADL= Acid detergent lignin; NDF = neutral detergent fiber

Table 8. Feed Intake (FI), body weight (BW) and weight gain (WTG) of the 14, 28 and 42 day old broilers.

Treatments	FI (g/bird/day)				BW (g)				WTG (g/bird/day)			
	14d	28d	42d	Overall	14d	28d	42d	Overall	14d	28d	42d	Overall
Diet 1	69.6	129.8	141.7	115.7	372	1079	2117	1190^{b}	58.3	89.4	76.1	74.6
Diet 2	71.7	127.4	163.1	120.7	401	1173	2161	1274^{ab}	60.1	87.0	94.6	80.6
Diet 3	80.8	162.0	165.3	136.0	418	1394	2328	1380^{a}	68.3	97.4	93.2	89.6
Diet 4	68.7	129	160.7	116.1	382	1104	2345	1277^{ab}	49.7	86.5	90.4	75.9
Diet 5	70.7	143.3	161.5	125.2	393	1270	2262	1308^{a}	60.9	97.2	92.8	83.6
Diet 6	74.3	120.6	161.7	118.9	402	1120	2011	1178^{b}	63.9	79.5	94.7	78.2
Diet 7	70.7	130	177.5	122.4	363	1162	2201	1242^{ab}	49.8	88.1	96.6	78.1
Diet 8	67	112.6	182.3	123.0	404	1128	2379	1303^{a}	57.4	72.3	106.4	78.7
Diet 9	69.3	134.8	165.7	123.3	383	1088	1990	1153^{b}	55.6	97.4	84.6	79.3
Diet 10	69.7	128.0	173.5	123.8	394	1229	1972	1198^{b}	59.7	87.6	99.6	82.3
Diet 11	64.	13802	175.6	125.9	335	1180	2092	1202^{b}	53.7	89.5	99.5	80.9
Diet 12	73.5	31.4	166.8	116.9	412	1154	2280	1282^{ab}	61.6	85.6	78.4	75.2
Overall	75.3^{a}	143.7^{b}	167.5^{c}		388^{a}	1173^{b}	2178^{c}		158.2^{a}	88.6^{b}	92.3^{b}	
ANOVA						probability						
Diet		NS				0.03				NS		
Age		0.0001				0.0001				0.0001		
Diet x Age		NS				NS				NS		

Table 9. Retained energy per kg of diet (REPKD), Basal metabolic rate per kg of diet(BMRPKD) and Net energy per kg of diet (NEPKD) for the14, 28 and 42 day old broilers.

Treatment	RETEPKD (kcal/kg)				BMRPKD (kcal/kg)				NEPKG (kcal/kg			
DIETS	14-d	28-d	42-d	Overall	14d	28d	42d	Overall	14-d	28-d	42-d	Overall
Diet 1	1830	1514	1510	1618	664	934	930	842	2493	2448	2441	2460
Diet 2	1837	1831	1694	1787	637	780	693	703	2474	2611	2387	2490
Diet 3	1753	1729	1694	1725	631	740	734	702	2384	2463	2461	2428
Diet 4	1620	1433	1581	1545	803	886	739	809	2423	2319	2321	2354
Diet 5	1724	1833	1820	1794	722	617	820	719	2446	2455	2640	2513
Diet 6	1749	1769	1687	1733	659	836	662	719	2409	2598	2349	2452
Diet 7	1656	1889	1744	1763	761	827	684	757	2416	2576	2428	2520
Diet 8	1576	1807	1826	1729	824	911	687	807	2400	2696	2514	2536
Diet 9	1667	1784	2054	1837	761	819	724	768	2429	2609	2778	2605
Diet 10	1656	1790	1951	185	691	731	776	732	2347	2600	2727	2558
Diet 11	1736	1869	1903	1815	734	711	638	694	2470	2518	2541	2510
Diet 12	1771	1807	1559	1725	654	679	889	740	2424	2527	2448	2466
Overall	1714	1757	1752		711	789	748		2350^a	2500^b	2550^b	
ANOVA					probability							
Diet	NS				NS				NS			
Age	NS				NS				0.05			
Diet x Age	NS				NS				NS			

Table 10. Efficiency of retained energy (REENEEF), maintenance energy (MAINTEEF) and Net Energy (NEEF) of the 14, 28 and 42 day old broilers.

Treatment	REENEEF (%)				MAINTEEF (%)				NEEF (%)			
	14d	28d	42d	Overall	14d	28d	42d	Overall	14d	28d	42d	Overall
Diet 1	0.59	0.48	0.47	0.51	0.22	0.30	0.29	0.27	0.81	0.78	0.76	0.78
Diet 2	0.59	0.58	0.52	0.56	0.21	0.25	0.21	0.22	0.80	0.82	0.74	0.78
Diet 3	0.57	0.55	0.52	0.54	0.21	0.23	0.23	0.22	0.78	0.78	0.75	0.77
Diet 4	0.53	0.44	0.49	0.49	0.26	0.28	0.23	0.24	0.79	0.74	0.72	0.75
Diet 5	0.56	0.58	0.57	0.57	0.23	0.19	0.25	0.23	0.79	0.78	0.82	0.79
Diet 6	0.57	0.56	0.54	0.54	0.23	026	0.20	0.23	0.78	0.82	0.72	0.77
Diet 7	0.54	0.60	0.55	0.55	0.24	026	0.21	0.24	0.78	0.86	0.75	0.80
Diet 8	0.51	0.56	0.54	0.54	0.26	0.29	0.21	0.25	0.78	0.85	0.77	0.80
Diet 9	0.54	0.56	0.58	0.58	0.25	0.26	0.22	0.24	0.79	0.82	0.85	0.82
Diet 10	0.53	0.59	0.57	0.57	0.22	0.23	0.24	0.23	0.76	0.82	0.84	0.80
Diet 11	0.56	0.57	0.57	0.57	0.24	0.22	0.20	0.22	0.80	0.82	0.76	0.79
Diet 12	0.57	0.58	0.55	0.55	0.22	0.21	0.27	0.23	0.79	0.80	0.76	0.78
Overall	0.55	0.55	0.54		0.23	0.25	0.23		0.78^{ab}	0.80^{b}	0.77^{a}	
ANOVA					probability							
Diet		NS					NS			NS		
Age		NS					NS			0.05		
Diet x Age		NS					NS			NS		

Table 11. Weight gain per body weight (WTGNPBW), heat production per kg of metabolic body weight per day (HPKMBW), and metabolizable energy (ME) consumed per unity body weight (MECONWT) of the 14, 28 and 42 day old broilers.

	Variables											
Treatments	WTGNPBW (g/g)				**HPKMBW $(kj/kg^{0.67})/d$**				MECONWT (kj/g)			
DIETS	14-d	28-d	42-d	Overall	14d	28d	42d	Overall	14d	28d	42d	Overall
Diet 1	0.49	0.26	0.11	0.29	680	853	608	713	7.6	5.0	2.9	5.2
Diet 2	0.48	0.24	0.14	0.28	686	615	629	643	7.3	4.6	3.3	5.0
Diet 3	0.52	0.24	0.13	0.29	783	801	598	727	7.8	4.9	3.0	5.3
Diet 4	0.41	0.25	0.12	0.26	706	878	532	705	6.2	4.9	2.8	4.6
Diet 5	0.49	0.24	0.13	0.29	749	660	558	655	7.4	4.7	3.1	5.1
Diet 6	0.50	0.21	0.15	0.29	757	639	558	686	7.6	4.5	3.5	5.2
Diet 7	0.43	0.24	0.14	0.27	700	591	663	647	6.7	4.7	3.4	5.0
Diet 8	0.45	0.20	0.14	0.27	772	592	650	668	6.8	4.2	3.5	4.8
Diet 9	0.46	0.28	0.13	0.29	766	794	640	681	7.4	5.6	3.4	5.0
Diet 10	0.48	0.23	0.16	0.29	769	602	484	659	7.3	4.4	3.8	5.2
Diet 11	0.51	0.24	0.15	0.30	728	710	596	678	7.8	4.9	3.6	5.5
Diet 12	0.47	0.24	0.11	0.27	720	640	591	650	7.3	4.8	2.8	4.9
Overall	0.47^{a}	0.24^{b}	0.13^{c}		734^{a}	698^{a}	596^{b}		7.9^{a}	4.8^{b}	3.2^{c}	
ANOVA					probability							
Diet	NS				NS				NS			
Age	0.0001				0.0001				0.001			
Diet x Age	NS				NS				NS			

Table 12. Efficiency of bird retained energy across the literature

RE	EFF (%)	DIET/INGREDIENT	BIRD	AGE/WT	REFERENCE
RE	0.31	LOWER ENERGY DIET	CHICKEN	32 DAYS	FARELL,1980
RE	0.38	HIGHER ENERGY DIET	CHICKEN	32 DAYS	FARELL,1980
RE	0.38	DIET	LEAN BROILER	7 WEEKS	WHITEHEAD, 2000
RE	0.38	DIET	FAT BROILER	7 WEEKS	WHITEHEAD, 2000
RE	0.39	DIET	LEAN BROILER	10 WEEKS	MCLEOD, 1987
RE	0.41	DIET	FAT BROILER	10 WEEKS	MCLEOD, 1987
RE	0.43	DIET	BROILER	6 WEEKS	GERAERT, 1987
RE	0.47	DIET	LAYER	2 WEEKS	SUGAHARA, 1992
RE	0.47-0.48	DIET	LAYING HEN	35 WEEKS	GABARROU, 1998
RE	0.49-0.50	TUBE-FED	LAYING HEN	35 WEEKS	GABARROU, 1998
RE	0.49-56	DIET	BROILER	2 WKS	PIRGOZLIEV, 2001

Table 13. Efficiency of bird net energy across the literature

NE	EFF (%)	DIET/INGREDIENT	BIRD	AGE/WT	REFERENCE
NE_{GAIN}	0.50	DIET	CHICKEN	32 DAYS	FARELL,1980
NE	0.64	CHAYALEAF	COCKEREL	3.15 KG	MCNAB, 2000
NE	0.86	WHEATLEAF	COCKEREL	3.15 KG	MCNAB, 2000
NE	0.81	DIET	LEAN BROILER	10 WEEKS	MCLEOD, 1987
NE	0.86	DIET	FAT BROILER	10 WEEKS	MCLEOD, 1987

CHAPTER V

THE EFFECTS OF FEED RESTRICTION FROM 8-20 WK ON RESPONSE TO HEAT STRESS AT 20 WK OF AGE

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ABSTRACT: An experiment was conducted to determine feed restriction termobalance of layers during cyclic-high ambient temperature exposure. The 20 week old H&N pullets used were allowed to consume feed ad libitum from hatching to 8 wk of age. At this time, birds were individually caged, divided into 4 groups and limit fed at 50, 65, and 80% of the 4th group's ad libitum feed consumption level. At 20 wk, birds averaged 805, 966, 1109, and 1251 g for the 4 feeding groups respectively. Birds were placed in individual cyclic temperature (24-38 °C) metabolic-respiratory chambers so that termobalance could be monitored. Variables monitored and results expressed as kcal/h/kg body weight$^{0.66}$ for the graded feeding levels and 24 vs 38 °C environments included heat production (15.0, 16.7, 17.2, 18.6 vs 15.6, 17.7, 19.0, 21.5 kcal/h/kg), evaporative cooling (6.1, 6.8, 6.5, 7.4 vs 11.2, 13.0, 12.4, 12.0 kcal/h/kg), nonevaporative cooling (9.4, 9.7, 10.4, 10.5 vs 4.3, 3.0, 4.6, 5.9 kcal/h/kg), and body heat content change (-.04, 0.2, 0.3, 0.2 vs 1.8, 1.8, 2.0, 2.2 kcal/h/kg).

The result indicated that heat production increased with bird body size level within the 24 and 38 °C environments. In addition, heat is preferentially dissipated as nonevaporative cooling (NEC) within the 24 °C environment, and at high ambient temperature of feeding level, the ability of pullets to compensate for the reduced nonevaporative cooling associated with high ambient temperature declined as body weight increases. The study showed that while HP increased with both increased body weight and ambient temperature, heat loss through NEC was 36.4% higher than the evaporative heat loss at ambient temperature. Conversely, evaporative heat loss as a mean of heat dissipation was 63.3% higher than the NEC in the heat distress environment.

Key words: layers, restricted feeding, thermobalance, heat production

INTRODUCTION

Being homeotherms, birds are less vulnerable to environmental temperature changes than poikilotherms with respect to metabolic function and avoiding tissue damage (Smith and Oliver, 1970). However, the price paid for this benefit is that relatively little body temperature fluctuation is required to dramatically and irreversibly deteriorate functional efficiency. The problem is generally more pronounced in larger birds since their body size increases only 0.66 as fast as body weight. As such, utilization of fed restriction to lower body size may impact bird high temperature tolerance.

The normal body temperature of the adult fowl falls in 41-42 °C range (Meltzer, 1983). In order to maintain this body temperature range when exposed to widely varying ambient temperatures, the bird must manipulate both physiological and metabolic mechanisms directed at controlling heat production and both sensible and insensible heat losses. When placed in lower and intermediate temperature environments, birds manage to dissipate heat by means of non-evaporative cooling system, a process by which the birds crouch or stand spreading wings away of the body (Sturkie, 1986). In this manner, the bird increases its surface area and allows large avenue for heat transport and dissipation. Once the ambient temperature exceeds the bird's thermoneutral zone, non-evaporative cooling processes decline and then, evaporative cooling system (respiratory insensible heat loss) becomes the major means of heat dissipation (Teeter and Belay, 1996). During this process, the bird pants and is able to considerably increase its respiration rate, thus making more efficient heat dissipation through evaporative cooling. Linsley and Berger (1964) reported that respiration rate can vary from 25 breaths per min in birds held in thermoneutral environments, to 250 breaths per minute in birds held in an acute heat stress environment. Researches have shown that at high temperature, the respiratory insensible heat loss may rise up to six times that of cutaneous heat loss (Van Kemp, 1974; Chwalibog et al., 1985).

Scott (1976) reported that reduced feed intake under heat stress conditions is due to a lower energy requirement because energy needed to keep the body warm and physical activities are reduced to a minimum, except for panting. It is well known that ingestion of feed causes increased heat production by the animal due to the "specific dynamic action" of the feed. Washburn et al (1980) found that restriction of food consumption over a period of several wk increased survival time of birds under heat stress when compared to the non-restricted fed ones.

Yahav and Plavnik (1998) have observed that broiler restricted to growth induced by feed restriction and later exposed to heat stress significantly increased breast yield and reduced abdominal fat even though weight gain, feed intake and feed efficiency were all depressed when compared to the control. The same authors later compared (1999) the beneficial effects of early-age thermal conditioning vs food restriction on the bird's performance and thermotolerance once exposed to subsequent heat stress, and they found that even though thermal conditioned birds displayed significantly better results in depressing plasma triiodothyronine concentration (thus reducing heat production), and in having lower boy temperature, feed restricted treated birds still performed better than the control.

Li et al. (1992) reported that while abdominal temperature varied little with food intake and environmental temperature below 28 ^{O}C in laying hens, it did increase with the above variables at temperature higher than 28 ^{O}C, suggesting that the heat production associated with feed consumption at the environmental temperature higher than 28 ^{O}C added a burden of heat to the layer hen to dissipate. The same authors found that within the increased environmental temperature, the bird metabolic rate increased regardless of the size of the food intake. Moreover, Yamamoto and Zhou (1998) and Teeter et al. (1992) have reported an increased heat production and abdominal temperature with increased food intake and high environmental temperature, whereas other studies have found that at high temperature, food restriction significantly reduced the rate of increase of rectal temperature (Francis et al., 1991; MacLeod and Hocking, 1993).

Feed restriction in broiler breeder gives rise to a reduced fasting heat production, due mainly to the bird reduced body weight: Siegel et al. (1994) reported that food restriction decreased plasma triiodothyronine (T_3) concentrations and lowered the surface temperature of the fed chick, suggesting a reduced activity and low heat production associated with the bird when compared to the full fed one.

The beneficial effects of genetic selection on the heat stressed's bird performance and welfare was highlighted in a study involving feed restriction applied early to dwarf and non dwarf chickens submitted to heat stress near the market age: non dwarf chickens significantly increased body weight and displayed a higher resistance to disease infection when compared to the dwarf chickens (Siegel et al., 1994). This observation was later supported by Zulkifli et al (1994; 2000) who found that early feed restricted chicks exposed later to heat stress significantly improved growth and survivability, had a reduced heterophil to lymphocyte ratio (H/L)- a reliable biological index of stress in avian species, and improved resistance to disease or infection when compared to the full fed birds.

A commonly observed result of feed restriction is an increase efficiency of feed utilization and reduced abdominal fat. However, little attention has been paid to the possibility that an adjustment of metabolic rate might contribute to this effect.

The objective of this study was to determine the effects of three restricted feeding levels on pullet heat distress tolerance.

MATERIALS AND METHODS

One day old H & N International pullets were fed a diet ad libitum (see Table 1) until 8 wk of age. From 8-20 wk of age, the pullets were divided into 4 groups, individually caged and limited fed at 50, 65, and 80% of the 4th group's ad libitum feed intake. During week 20 post hatching, 3 birds per treatment were selected for body weight similarity to the treatment groups. The pullets averaged 805.3, 966.4, 1109.2 and 1251.2 g for 50, 65, 80, and fed ad libitum groups, respectively. The selected birds were then aseptically prepared and implanted in the abdominal cavity with a radiotelemetry temperature transmitter[1] as described in the Dataquest III User's Manual of data Sciences Inc[2]. Following 3 days of surgical recovery, birds were placed in 12 individual respiratory chambers and allowed a 3-day adjustment period to chambers.

On the treatment day, birds on the restricted treatments were offered 33, 43, and 52 grams of feed which corresponded to 50, 65 and 80% of the average feed consumed by ad libitum birds in the previous 3 days. For the full fed group of birds, the feed was offered ad libitum. The composition of the rations experiment is given in Table 1.

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[1] Mini-mitter telemetry System, Sunriver, Oregon 97707

[2] St. Paul, MN 55113, Document no. 10000-05, 1988

The 6 h experiment consisted of 2 h thermoneutral temperature (24 °C) followed by an increase of 3.5 °C /hr until a target temperature of 38 °C was reached.

Respiratory Chambers

The description of the respiratory chambers has been provided by Wiernusz and Teeter (1993). The 13 (12 test and 1 reference) open circuit respiratory chambers (51 x 34 x 41 cm), constructed of clear acrylic Plexiglas (63.5 mm) were equipped with wire mesh floors suspended 9 cm above an excreta collection pan (51 x 34 cm) containing 4 cm of mineral oil. The oil was used to ensure that excreta moisture was isolated from the chamber environment. Each compartment also contained a 3-cm fan[3] to mix air, and an ambient temperature probe[4] to monitor chamber temperature per minute per chamber throughout the experiment. Overall chamber calibration was established by comparing heat liberation estimated by comparing slaughter data (McDonald, 1993) and also by ethanol oxidation according to Misson (1974). Both methods yielded values within 2 and 1% of indirect calorimetry.

Breathing Air Supply and Analysis.

Compressed air dried to a 4 C dew point was delivered to the birds for respiration through individual 64-mm-diameter polyethylene lines. Each line passed through a computer-monitored and controlled heat exchanger such that air reached the desired temperature prior to chamber entry. Independent microvalves were used to regulate chamber air flow (5 L/min ± .005) with flow rate monitored using an electronic

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[3] Radio Shack cooling fan Catalog Number 273-244, Radio Shack, Stillwater, OK 74075

[4] Model ES-060, Omnidata International, Logan, UT 84321

mass flow meter [5]. Oxygen, CO_2 and H_2O vapor concentrations were determined five times per hour per chamber by Ametec[6] (respectively.

Heat Production .

Oxygen consumption and CO_2 production were estimated by multiplying chamber air flow rate by the differential gas concentration between reference and test chambers. Heat production (kilocalories per hour per MWT) was estimated from liters of O_2 consumed and liters of CO_2 produced according to Brouwer equation (1965):

$$HP\ (kcal) = (16.18\ O_2\ consumed + 5.02\ CO_2\ produced)/4.184.$$

No correction was utilized for nitrogen excretion, as the error created by its omission is about .2% (Romjin and Lokhorst, 1961, 1966).

Insensible Heat Loss or Evaporative Heat Loss (EVC)

Bird evaporative heat loss (respiratory + cutaneous) was estimated by coupling evaporative losses (g) with the latent heat of vaporization (2.427 kj/g H_2O; Sturkie, 1986) To estimate evaporative losses, water vapor production was estimated by first converting relative humidity (RH) into grams of water per cubic liter for test and reference chambers. Total bird water vapor production (respiratory plus cutaneous) was determined by multiplying test and reference chamber differential water vapor concentration by the flow rate. To accomplish this, air weight (g/l^3) at saturation for various ambient temperature (AOAC, 1987) was regressed against ambient temperature and the resulting equation: given below was used to estimate g H_2O at saturation:

$$Air\ weight\ (or\ Sat\ H_2O) = 8{,}694 - 0.218391 \times T + 0.03145 \times T^2$$

Bird evaporative heat losses per minute was then estimated as:

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[5] Omega Engineering, Stanford, CT 06907

[6] Pittsburgh, PA 15238) O_2 (accuracy ± .03%

H_2O = Sat H_2O x (RH/100) x 0.001

Bird H_2O evaporative losses were then estimated as:

H_2O prod = (flow$_{test}$ x H_2O_{test}) – (flow$_{ref}$ x H_2O_{ref}) x 60

H_2O prod = water production (g/min)

T=test chamber

Ref=reference

The total evaporative heat losses (respiratory water and cutaneous) was calculating by multiplying the estimated evaporative water loss by the latent heat of vaporization

Sensible Heat Loss (S) or NonEvaporative Heat Loss (NEV).

Sensible heat loss (kilocalories per MWT per hour) was estimated by difference according to Yousef (1985): S=HP-EVC ± HC

Body Heat Content (HC).

Changes in bird heat content was monitored by coupling body temperature (BT) recorded every 1.5 minutes, with bird specific heat as described by Sturkie (1986). The mean specific heat of body tissue was 3.5 kj/kg/ ^{o} C (Sturkie.,1986).

All data measurements were controlled and monitored using a workhorse data Acquisition and Control System[7]. Gas concentration (RH, O_2 and CO_2) quantifications, flow rate, and ambient temperature were recorded once on each of the 12 compartments every 12 minutes.

Statistical Analysis

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[7] Omega Engineering, Stanford, CT 06970

Response variables such as oxygen, CO_2, water concentrations, HP, NEV, EVC, BT and HC were regressed against time in order to establish polynomial equations that describe the data. Quantitative estimates for each variable attributed to bird metabolism were made by integrating variable functions over specified time intervals, and by adjusting for the control chamber as appropriate. All integrated values as well as BT and water consumption means were analyzed by ANOVA using the General Linear Models procedure of the SAS Institute (1985). When a significant F statistic was noted, treatment means were separated by Duncan's multiple range tests (Steel and Torrie, 1960).

RESULTS AND DISCUSSION

The study showed that heat production (HP) decreased ($P<0.05$) in a linear fashion as feed restriction extent increased when compared to the full fed birds (Table 2). The results showed that the reduction in HP was positively correlated with the degree of feed restriction, and this finding agreed with what has been reported by some others (MacLeod and Shannon., 1978) that the heat production was 7% lower in the restricted birds than in the control group. The HP of the 65% restricted fed group didn't significantly differ from that of 80% group. Both NEV and EVC were higher for the control group than for the feed restricted groups. However, there was no significant difference between 80% and the full fed birds. Feed restriction had no significant effect on any of the BT and HC measurements.

There was an increased of HP during the interval of heat distress (HD). However, there was no significant difference between interval 1 (24 °C) and 2 (24-31 °C), but a significant increase was observed during the interval 3 (31-38 °C) when HP increased from 16.91 to 18.44 (Table 3). The increase of heat production during HD has been observed in previous studies (Van Kampen, 1974; Wiernusz, 1991), and Barrot and Pringle (1946) have suggested that it is related to the energy cost of panting. The NEV decreased linearly with increasing ambient temperature, whereas EVC did increased linearly (Table 3). The observed decreased NEV, which is due to the reduced bird-environmental temperature differential has been reported in a previous study (Olson et al, 1974). It appeared that the lowered NEV has forced the bird to enhance other means of heat dissipation mechanisms such as increasing ECV. Furthermore, the increased heat production during heat stress has given rise to an increase in BT and HC. The rate of increase of BT with increasing air temperature over the TN zone has been reported to be dependent on the severity of the air temperature (Freeman, 1971; and Arieli et al., 1980). It was obvious that HP, NEV, EVC, and HC values from the *ad libitum* birds were constantly different form the values recorded in the food restricted birds: the *ad libitum* birds had higher values.

The study indicated that as the ambient temperature rose, the extent of NEC declined and this has been previously demonstrated by some researchers (Van Kampen, 1974., Sturkie 1986) to be due to the reduced difference temperature between the bird body temperature and the environment. Once the heat distress prevails in the environment and creates a heat load for the bird to dissipate, the latter increased EVC mechanism of heat dissipation

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Table 1. Composition of rations fed during the experimental period.

	Rations (%)		
Ingredients	Starter	Grower	Finisher
Ground Corn	64.09	60.39	62.30
Soybean meal (44%CP)	29.10	17.00	25.00
Wheat middling	3.22	19.01	6.00
Dicalcium phosphate	1.73	1.20	1.50
Limestone	1.00	1.50	4.20
Salt	0.40	0.30	0.40
Vitamin mix[1]	0.30	0.30	0.30
DL-Methionine, 99%	0.11	0.20	0.20
Trace mineral mix[2]	0.05	0.10	0.10
Calculated Analysis			
ME (kcal/kg)	2,860	2,750	2,758
Crude protein (%)	19.00	15.97	17.58
Calcium (%)	0.90	0.95	2.08
Phosphorus total (%)	0.47	0.37	0.42

[1] The Vitamin mix contained per kilogram: vitamin A, 3,968,280 IU.; Vitamine D_3, 1, 102,300 IU; .vitamine E, 13,228 IU; vitamine B12, 7.9 mg; riboflavin, 2,646 mg; niacin, 17,637 mg; d-pentatonic acid, 4,409 mg; chorine, 200,178 mg; menadione, 728 mg; folic acid, 441 mg; pyridoxine, 1,587 mg; thiamin, 794 mg; d-biotin, 44 mg

[2] Mix contained manganese, 12.0%; zinc, 10.0%; Iron, 7.5%; copper, 1.0%; iodine, .25%; calcium, 13.5%

Table 2. Effects of feed consumption level on pullet heat production (HP), nonevaporative (NEV) and evaporative EVC) heat production, body temperature (BT) and heat content (HC).

	Feeding level (% of ad libitum)			
Heat Production	50	65	80	100
HP (kcal/mwt/h)	3.61^a	4.06^b	4.28^b	4.78^c
NEV (kcal/mwt/h)	1.65^a	1.58^a	1.77^{ab}	1.96^b
EVC (kcal/mwt/h)	2.03^a	2.27^{ab}	2.25^{ab}	2.44^b
BT (C)	41.06^a	41.7^a	41.6^a	41.6^a
HC (kcal/mwt/h)	0.19^a	0.22^a	0.26^a	0.26^a

$^{a-c}$ Means within a row with unlike superscript differ significantly *(P <0.05)*

Table 3. Effects of ambient temperature (T) on pullet heat production (HP), nonevaporative(NEV) and evaporative (EVC) heat production, body temperature (BT) and heat content (HC).

	Ambient Temperature (^{o}C)		
Heat Production	24	24 – 31	31 – 38
HP (kcal/mwt/h)	4.04^{a}	4.10^{b}	4.40^{c}
NEV(kcal/mwt/h)	2.53^{a}	1.75^{b}	1.04^{c}
EVC (kcal/mwt/h)	1.61^{a}	2.22^{b}	2.83^{c}
BT(^{o}C)	41.03^{a}	41.46^{b}	42.35^{c}
HC (kcal/mwt/h)	0.04^{a}	0.02^{b}	0.45^{c}

$^{a\text{-}c}$Means within a row with unlike superscript differ significantly ($P < 0.05$)

Table 4. Effects of feed restriction level (FRL)[1] and temperature interval (INT)[2] on pullet heat production (HP), nonevaporative (NEV) and evaporative (EVC) and heat content (HC).

FRL (%)	INT	HP (kcal/mwt/h)	NEV (kcal/mwt/h)	EVC (kcal/mwt/h)	HC (kcal/mwt/h)
50	1	3.61^a	2.25^a	1.46^a	-0.01^a
50	2	3.51^a	1.67^b	1.91^a	0.08^b
50	3	3.73^a	1.03^c	2.68^b	0.43^c
65	1	3.99^a	2.32^a	1.63^a	0.04^a
65	2	3.51^a	1.67^b	2.10^a	0.26^b
65	3	4.23^b	0.72^c	3.11^c	0.42^c
80	1	4.11^b	2.49^a	1.55^a	0.08^a
80	2	4.16^b	1.72^b	2.20^a	0.26^b
80	3	4.54^c	1.10^c	2.96^c	0.48^c
100	1	4.45^c	2.51^a	1.77^a	0.05^a
100	2	4.73^c	1.94^a	2.68^b	0.25^b
100	3	5.11^c	1.72^a	2.58^b	0.52^c
TRT		0.0001	NS	NS	NS
INT		0.03	0.0001	0.0001	0.0001
TRT*INT		NS	NS	NS	NS

[a-c] Means within a column with unlike superscript differ significantly ($P < 0.05$)

[1]= Feed restriction level (%)

[2] INT=- Interval

1=constant temperature (24°C)
2= cyclic temperature (24-31°C)
3=cyclic Temperature (31-38°C)

Table 5. Effects of feed restriction level (FRL)[1] and interval temperature (INT)[2] on pullet body weight (BW) and body temperature (BT).

FRL (%)	INT	BW (kg)	BT1[3] (°C)	BT2[4] °C)
50	1	0.84^{a}	41.07^{a}	41.05^{a}
50	2	0.84^{a}	41.07^{a}	41.04^{a}
50	3	0.84^{a}	41.07^{a}	42.30^{b}
65	1	1.036^{b}	41.0^{a}	41.10^{a}
65	2	1.036^{b}	41.0^{a}	41.50^{a}
65	3	1.036^{b}	41.0^{a}	42.30^{b}
80	1	1.211^{c}	40.8^{a}	41.00
80	2	1.211^{c}	40.8^{a}	41.40
80	3	1.211^{c}	40.8^{a}	42.30^{b}
100	1	1.508^{c}	40.9^{a}	41.00^{a}
100	2	1.508^{c}	40.9^{a}	41.40^{a}
100	3	1.508^{c}	40.9^{a}	42.30^{b}

$^{a\text{-}c}$ Means within a column with unlike superscript differ significantly ($P < 0.05$)

[1]= Feed restriction level (%)
[2] INT=Interval of temperature exposure
[2]1 = constant temperature (24°C)
2 = cyclic temperature (24-31°C)
3 = cyclic Temperature (31-38°C)
[3] = pullet body temperature before exposure to temperature treatment
[4]= pullet body temperature after exposure to temperature treatment

CHAPTER VI

EFFECTS OF LIGHTING PATTERN AND FEED RESTRICTION DURING THE GROWING PERIOD ON FASTING HEAT PRODUCTION IN LAYING HENS.

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ABSTRACT An experiment was conducted to determine the effects of lighting pattern on fasting heat production (FHP) of pullets raised under feed restriction program during the growing phase. From 0 to 28 wk of age, the birds were divided into four groups and they were limited fed at 50, 65, and 80% of the fourth group's ad libitum intake. From each feeding treatment, 6 pullets were transferred to open circuit respiratory chambers for 3 days of adaptation. A lighting pattern of 12 h-dark followed by 12 h-light was maintained within the chambers. The birds were then fasted for 6 h, which were followed by 2 d of feed removal. Gas data (oxygen consumption and carbon dioxide production) were monitored during the last 48 h of feed removal.

The study found no significant impact of limited feeding levels on either FHP or respiration quotient (RQ). However, lighting pattern and length of feed removal (day 1 vs day 2) showed significant effects on FHP ($P < 0.001$ and $P < 0.01$, respectively). Pullets held in the light environment had 32.6% higher FHP than those held in the dark, whereas FHP measured during the first 24 h was 17% higher than that measured during the second 24 h. The RQ was significant different during the two fasting days ($P < 0.001$), with higher RQ observed on the first day (0.77) than the second day (0.71). There were no interactions among feeding levels, fasting duration, or lighting pattern.

The exponential relationships between the log BW and log FHP at the end of the experiment (48 h) were 0.65 and 0.70 in the dark and light environments, respectively. This confirms the use of the 2/3 power to relate FHP to BW.

Key words: pullet, feed restriction, lighting pattern, heat production, respiratory quotient.

INTRODUCTION

Fasting heat production (FHP) and basal metabolic rate (BMR) are considered potential indicators of the bird growth's efficiency, with lower values suggest that the birds allocate more energy for production compared to their counterpart birds fed equivalent quantity of feed that likely spend much of their energy for maintenance. As BMR is an intrinsic characteristic of the animal, its best values are obtained when the bird is maintained in a resting post-absorptive state, good nutritive state, awake and in a sitting position, sexually and emotionally in repose, and in a thermoneutral environment (Luiting, 1990; Kuenzel and Kuenzel, 1977). However, all these requirements are not completely under control, and as result, FHP rather than BMR are usually measured, considering that the activity and the post-absorptive state are the key differences between those measurements.

Feed restriction programs have been successfully applied in laying hen nutrition to limit BW, improve reproductive performance, and to increase both egg production and egg quality. However, studies conducted on the effects of feed restriction on FHP have produced mixed results. Fuller and Dunahoo (1962) observed reduced FHP in fed restricted layer strain hens, whereas Balnave et al. (1979) found increased FHP in same strain of pullets within a similar degree of feeding. On the other hand, Farrell and Johnson (1984) found no alteration in FHP due to feed restriction in laying hens held in conditions that minimize physical activity (i.e., complete darkness). Other studies have found a variation in FHP of 4-33% between strains and of 5-13% among individuals. It appears that the genetic make-up of the bird, activity, environmental temperature, length and level of feed restriction influence the magnitude of the FHP reduction (Van Kampen, 1976; Geers et al., 1978; Lundy et al., 1978). The obvious impact of genetic or heritability of on bird FHP was reported by Damne et al. (1986_b) who found no differences between two strains of breeds, but their reciprocal crosses displayed significant lower ($P<0.05$) FHP than their parent.

The time the birds reach the post-absorptive state is usually determined by the presence of green color within their feces (bile presence), or by respiratory quotient (RQ; the ratio of carbon dioxide produced / oxygen consumed) value close to 0.70 (Lundy et al., 1978). However, studies have shown that BW, and time required to reach a minimum post-absorptive state (24-120 h) or to get a RQ values close to 0.70 can vary within and between bird species (Van Kampen, 1974; Chwalibog, 1991). Misson (1974) fasted birds 24 h and found RQ value of 0.705 for birds weighing less than 2.5 kg, and 0.728 in the birds weighting more than 2.5 kg.

Factors such BW (Geers et al., 1978), activity (Van Kampen, 1976), sex and reproductive condition (Balnave et al., 1979), duration of feed withdrawal (Geers et al., 1978), age (Lesson and Porter-Smith, 1972), circadian variation, breeds (Lundy et al., 1978;), and feather insulation (Tullet et al., 1980) have been reported as the main causes of variation in birds' FHP. In this context, a difference of 37% in FHP was observed between laying and non-laying hens, and a videotape recording of activity has shown that the most efficient birds (those with lowest FHP) spent most time resting (58 vs 50% of the day), less time standing (42 vs 50%), and were less sensitive to disturbances (70 vs 89%) than the less efficient birds (Morrison and Leeson, 1978; Van Kempen, 1981). Therefore, it is likely that a plan of feed restriction supplemented with melatonin (a sleepinducing hormone) and applied to laying hens or baby chicks would likely allow the birds to save energy and improve their performance during long distance transportation.

Lighting pattern has a large impact on the bird performance and heat production. Buyse (1997) observed that an intermittent lighting program resulted in a 6% improvement in broiler feed efficiency and nitrogen retention when compared to the broilers raised in a continuous lighting system. A similar observation was reported by Apeldoorn et al. (1999), who suggested that the observed better performance was likely due to lower physical activity recorded in the intermittent-light held birds, when compared to those in the continuous lighting system. Regardless of the nutritional status of the bird, heat production differences of 22-50% have been observed between various lighting systems (Lundy et al., 1987; McLeod et al., 1980). Lewis et al., (1994) found that heat production in darkness is usually 25 to 30 % lower than that in light, and Damne et al. (1986) found a FHP reduction of 27% in laying hens held in dark compared to those held in light. Studies conducted with ad libitum fed birds (Li et al, 1990) reported that the birds held in the dark had 33% lower fed heat production than those in the light. The same authors observed that about 76% of the heat difference from lighting system was associated with activity and posture.

Intermittent lighting (1L:2D) has also been shown to improve the broiler performance and energy saving (Leeson and Ohtani, 2000), in that birds held in the intermittent environment had a significant increase BW, ME_n, and a significant lower heat production after 8 wk compared to the birds maintained in the continuous lighting program.

This study was conducted to measure the effects of feed restriction during the growing period on the fasting metabolic rate of laying hens held in light and dark.

MATERIALS AND METHODS

Birds and management

One-day old H & N pullets were reared in floor pens of one of a poultry house located at the University's Poultry Research Center. The birds were raised on a feed restriction program consisting of 50, 65, 80% or ad libitum (see Table 1), and all treatment were allowed free access to water. At 28 wk of age, 24 birds (6 birds per treatment) were selected for nearly similar BW within their respective treatments and were transferred individually to respiratory chambers (as described by Wiernusz and Teeter, 1993) for adaptation. An alternating lighting pattern of 12 h dark followed by 12 hour of light during was imposed during the 2 days of the trial within the respiratory chambers.

Experimental procedure

Following the 3 days of acclimatization in the metabolic chambers, the birds were weighted and then starved for 24 h. As body weight, the pullets averaged 1317.17, 1445.00 1511.67 and 1600 g for 50, 65, 80%, and fed ad libitum groups, respectively. After the preliminary short starvation period, gas data were monitored during the following 48 h for further calculation of pullet FMR and RQ among the treatments.

Respiratory Chambers

The description of the respiratory chambers was provided by Wiernusz and Teeter (1993). The 13 (12 test and 1 reference) open circuit respiratory chambers (51 x 34 x 41 cm), constructed of clear acrylic Plexiglas (63.5 mm) were equipped with wire mesh floors suspended 9 cm above an excreta collection pan (51 x 34 cm) containing mineral oil to a depth of 4 cm. The oil was used to ensure that excreta moisture was isolated from the chamber environment. Each compartment also contained a 3-cm fan (Radio Shack cooling fan Catalog Number 273-244, Radio Shack, Stillwater, OK 74075) to mix air, and an ambient temperature probe (model ES-060, Omnidata International, Logan, UT 84321) to monitor chamber temperature per per minute per chamber throughout the experiment. Overall chamber calibration was established by comparing heat liberation estimated by comparing slaughter data (McDonald, 1993) and also by ethanol oxidation according to Misson (1974). Both methods yielded values within 2 and 1% of indirect calorimetry.

Breathing Air Supply and Analysis.

Compressed air dried to a 4 C dew point was delivered to the birds for respiration through individual 64-mm-diameter polyethylene lines. Each line passed through a computer-monitored and controlled heat exchanger such that air reached the desired temperature prior to chamber entry. Independent microvalves were used to regulate chamber airflow (5 L/min ± .005) with flow rate monitored using an electronic mass flow meter (Omega Engineering, Stanford, CT 06907). Oxygen, and CO_2 were determined five times per hour per chamber by Ametec (Pittsburgh, PA 15238) O_2 (accuracy ± .03%), respectively.

Heat Production.

Oxygen consumption and CO_2 production were estimated by multiplying chamber air flow rate by the differential gas concentration between reference and test chambers.

Heat production (kilocalories per hour per MWT) was estimated from liters of O_2 consumed and liters of CO_2 produced according to the equation of Brouwer (1965) as:

$$HP = 16.18\ O_2 \text{ consumed} + 5.02\ CO_2 \text{ produced.}$$

No correction was utilized for nitrogen excretion, as the error created by its omission is about 0.2% (Romjin and Lokhorst, 1961, 1966).

Statistical analysis

Chamber oxygen and CO_2 were regressed against time, time squared and time cubed such that polynomial equations describing the data were generated. Quantitative estimates for each variable were made by integrating variable functions over specific time intervals (light pattern) and adjusting for the control chamber as appropriate. All the integrated variables were analyzed by the analysis of variance (ANOVA) using the General Linear Model procedure (SAS Institute, 1982). When a significant F statistic was noted, treatment means were separated by Duncan's multiple range test (Steel and Torrie, 1960).

RESULTS AND DISCUSSION

The results indicate that the different feed restriction levels in the present study showed no significant effects on pullet FHP expressed per unit of metabolic size (Table 2). Since the birds were of the same strains, same age, and were held within the same environment that minimizes the activity, little variation in fasting heat production would be expected. Similarly, Balnave (1979) found no difference in FHP between birds raised under prolonged and severe feed restriction and full fed birds. Indeed, Siegel et al.(1996) have shown that the chyme content of the chick intestine after 24 h of feed removal were about half that of chick fed ad libitum, implying that both birds still have a supply of nutrients that partially sustain FHP and thus allowing a reduction in fat mobilization from extra-hepatic stores. Farrell and Johnson (1984) indicated that feed restriction applied to birds of different physiological or chronological ages doesn't alter FHP measured under conditions that minimized physical activity. Nonetheless, the effect of feed restriction on bird FHP has resulted in conflicting results in the literature in that FHP has either increased FHP (Balnave, 1976), or decreased it (Fuller and Dunahoo, 1962), when compared to the full fed birds.

The duration of fasting (48 h) had a significant effect ($P<0.01$) on the pullet FHP. The FHP was reduced by 17% FMR at the end of the second day of fasting, when compared to the FHP after the first 24 h of fasting (Table 3). This was likely due not only to pullet reduced body weight, but also to the depletion of feed/nutrients stored in the crop and intestines of the bird after a long period of feed removal. Additionally, a significant effect of lighting program on FHP was observed. Pullets held in the light had FHP 32.6 % higher than their counterparts maintained in the dark (Table 4). Similar variation in FHP has been reported in studies investigating distinct lighting systems (Damne et al., 1987; Van Kampen, 1976) and is largely attributed to differences in affinity associated with lighting program.

Activities such as preening, sitting, and standing, coupled with the genetics of the birds are sources of variations in FHP between and within strains of birds (Farrell and Johnson, 1984; Van Kampen, 1976; Lundy et al., 1987). An estimate of 33% of the FHP variation between two strains is reportedly due to differences in activity or energy expended for muscular activity (MacLeod et al., 1988). Damne et al. (1987) investigated the effects of lighting on FHP within same strain of hens and found that FHP was significantly higher (27.4%) during daylight when compared to their counterparts monitored in the dark. Damne et al. (1987) also observed a 3% increase in FHP in standing pullets when compared to the pullets that were sitting.

There were no significant effects of feed restriction levels on the bird RQ in the present study. However, RQ was significant higher ($P<0.05$) during the first day of fasting (0.77) when compared to the second day when RQ was 0.71 (Table 4). These RQ values suggest a gradual depletion of nutrients stored by the pullet, and a catabolism of fat and protein tissues to yield an RQ close to 0.70. These values fall in the normal range of RQ usually measured in the fasting birds (Farrell and Johnson, 1984). Nonetheless, fluctuation in nutrient supply such as the skip-a-day feeding program may result in RQ values beyond the established values. Leeson et al. (1990) observed an RQ value of 0.67 in fasting birds under a skip-a-day feeding program, and a value of 1.05 during the feeding stage of the program of skip-a-day feeding. The latter value (high one) was likely due fatty acids synthesis from carbohydrates during the first hours after feeding within the skip-a-day group of birds, whereas the lower RQ values recorded imply that the bird has reached the post-absorptive state and it was catabolizing fat and/or protein. No lighting effect was observed on the pullet RQ, and this suggest that the level of activity from the two groups of fasted pullets was nearly identical in both environments.

Interactions among feed restriction level, day, and lighting program were lacking in the current study (Tables 5 and 6). However, when lighting was used as a covariate with feed restriction, a significant effect of feed restriction on FHP ($P<0.01$) was observed. Likewise, the effects of CO_2 production ($P<0.02$) and O_2 consumption ($P<0.01$)

on FHR were found to be significant. The increasing FHP recorded in birds held within the same lighting environment and raised on an increasing level of feed consumption during the growing phase may stem from either higher FHP required to maintain heavier bird resulting from less restricted feeding plan, or to higher quantity of feed stored in the pullet reared on higher level of feed during the growing period. The study also found also that the levels of the gas produced (CO_2) and consumed (O_2) were significantly higher in the light than in the dark environment and this was linked to the increased activity within the light environment. Concomitantly, a trend of increasing CO_2 produced and O_2 consumed was also observed with increasing feeding level within the same environment pattern (Table 6).

The study shows that at the end of the fasting period, the determined exponent used to describe the relationships between FHP and pullet body weight fell in the ranges of the normal values reported in the literature (Brody, 1945; Thonney, 1990). The power of the exponent was of 0.65 in the pullets monitored in the dark, and 0.70 for those held in the light, respectively.

In conclusion, the present study showed that while feed restriction displayed no impact on pullet fasting heat production, lighting patterns did. Pullets held in the dark during the fasting period were allowed to save 32.6 % more energy than their counterparts held in the light. In addition, the study indicated that the longest the fasting period is extended (48 h vs 24 h), the highest the bird energy balance is negatively: a significant lower RQ close measured after 48 h (0.71 vs 0.77) suggested that the pullet has reached the post-absorptive state, has depleted the nutrient stored and now relied on the catabolism of fat and protein tissues to provide energy required for vital minimal activity to maintain continuous life.

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Table 1. Composition of rations fed during the experimental period.

	Rations (%)		
Ingredients	Starter	Grower	Finisher
Ground Corn	64.09	60.39	62.30
Soybean meal (44%CP)	29.10	17.00	25.00
Wheat middling	3.22	19.01	6.00
Dicalcium phosphate	1.73	1.20	1.50
Limestone	1.00	1.50	4.20
Salt	0.40	0.30	0.40
Vitamin mix[1]	0.30	0.30	0.30
DL-Methionine, 99%	0.11	0.20	0.20
Trace mineral mix[2]	0.05	0.10	0.10
Calculated Analysis			
ME (kcal/kg)	2,860	2,750	2,758
Crude protein (%)	19.00	15.97	17.58
Calcium (%)	0.90	0.95	2.08
Phosphorus total (%)	0.47	0.37	0.42

[1] The Vitamin mix contained per kilogram: vitamin A, 3,968,280 IU.; Vitamine D_3, 1, 102,300 IU; .vitamine E, 13,228 IU; vitamine B12, 7.9 mg; riboflavin, 2,646 mg; niacin, 17,637 mg; d-pentatonic acid, 4,409 mg; chorine, 200,178 mg; menadione, 728 mg; folic acid, 441 mg; pyridoxine, 1,587 mg; thiamin, 794 mg; d-biotin, 44 mg

[2] Mix contained manganese, 12.0%; zinc, 10.0%; Iron, 7.5%; copper, 1.0%; iodine, .25%; calcium, 13.5%

Table 2. Effects of feed restriction (FRL) during the growing phase on pullet CO_2 produced, O_2 consumed, heat produced (FHP) and respiratory quotient (RQ) during the fasting period.

	Feed Restriction Level (%)			
Variables	50	65	80	100
CO_2 prod (l/mwt/h)[1]	0.98^{a}	11.06^{a}	1.15^{a}	1.19^{a}
O_2 cons (l/mwt/h)	1.34^{a}	1.46^{a}	1.57^{a}	1.61^{a}
FHP[2] (kj/mwt/h)	26.57^{b}	28.87^{b}	31.08^{b}	31.98^{b}
RQ[3]	0.74^{a}	0.73^{a}	0.74^{a}	0.75^{a}

[a-b] Means within a row with unlike superscript differ significantly ($P < 0.05$)
[1] = metabolic body weight= $BW^{0.66}$
[2] = Fasting metabolic rate
[3] = Respiratory quotient (the ratio of carbon dioxide produced to oxygen consumed).

Table 3. Effects of lighting pattern on pullet CO_2 produced, O_2 consumed, heat produced (FHP), and respiratory quotient (RQ) during the fasting period.

	Lighting Pattern	
Variables	Dark	Light
CO_2 prod (l/mwt/h)[1]	0.90^a	1.29^b
O_2 cons (l/mwt/h)	1.20^a	1.79^b
FHP[2] (kj/mwt/h)	23.86^a	35.38^b
RQ[3]	0.73^a	0.75^a

$^{a\text{-}b}$ Means within a row with unlike superscript differ significantly ($P < 0.05$)

[1] = metabolic body weight= $BW^{0.66}$

[2] = Fasting metabolic rate

[3] = Respiratory quotient (the ratio of carbon dioxide produced to oxygen consumed).

Table 4. Effects of fasting duration on pullet CO_2 produced, O_2 consumed, heat produced (FHP), and respiratory quotient (RQ).

Variables	Fasting Duration Day 1	Day 2
CO_2 prod (l/mwt/h)[1]	1.21^a	0.98^a
O_2 cons (l/mwt/h)	1.60^a	1.37^a
FHP[2] (kj/mwt/h)	32.03^a	27.22^b
RQ[3]	0.77^a	0.71^b

[a-b] Means within a row with unlike superscript differ significantly ($P < 0.05$)
[1] = metabolic body weight= $BW^{0.66}$
[2] = Fasting metabolic rate
[3] = Respiratory quotient (the ratio of carbon dioxide produced to oxygen consumed).

Table 5. Effects of feed restriction (FRL)[1] and length of fasting(Day) on pullet heat production (FHP) and respiratory quotient (RQ).

FRL (%)	Day	CO_2 prod (l/mwt/h)	O_2 cons (l/mwt/h)	RQ[3]	FHP[2] (kj/mwt/h)
50	1	1.04^{a}	1.40^{a}	0.76^{ab}	27.8^{ab}
50	2	0.92^{a}	1.28^{a}	0.72^{a}	25.3^{a}
65	1	1.17^{ab}	1.55^{ab}	0.76^{ab}	30.9^{b}
65	2	0.95^{a}	1.36^{a}	0.70^{a}	26.8^{a}
80	1	1.28^{b}	1.73^{b}	0.76^{ab}	34.5^{c}
80	2	1.01^{a}	1.40^{a}	0.72^{a}	27.7^{ab}
100	1	1.35^{b}	1.74^{b}	0.79^{b}	34.9^{c}
100	2	1.04^{a}	1.47^{a}	0.71^{a}	29.7^{ab}
FRL		NS	NS	NS	NS
DAY		0.003	0.04	0.001	0.02
FRL*DAY		NS	NS	NS	NS

[a-c] Means within a column with unlike superscript differ significantly ($P < 0.01$)

[1] = Feed restriction

[2] = Fasting metabolic rate

[3] = Respiratory quotient (the ratio of carbon dioxide produced to oxygen consumed).

Table 6. Effects of feed restriction (FRL)[1]and lighting pattern on pullet fasting heat production (FHP) and respiratory quotient (RQ).

FRL[1] (%)	Lighting	CO_2 prod (l/mwt/h)	O_2 cons (l/mwt/h)	RQ[3]	FHP[2] (kj/mwt/h)
50	Light	1.17^{b}	1.60^{b}	0.75^{ab}	31.9^{c}
50	Dark	0.79^{a}	1.06^{a}	0.74^{ab}	21.2^{a}
65	Light	1.23^{b}	1.69^{b}	0.73^{a}	33.5^{c}
65	Dark	0.89^{a}	1.22^{a}	0.73^{a}	24.3^{a}
80	Light	1.33^{bc}	1.88^{c}	0.76^{b}	37.1^{c}
80	Dark	0.96^{ab}	1.25^{a}	0.73^{a}	25.1^{b}
100	Light	1.43^{bc}	1.97^{c}	0.77^{b}	39.1^{c}
100	Dark	0.96^{ab}	1.24^{a}	0.73^{a}	24.8^{b}
ANOVA					
FRL		0.02	0.01	NS	0.01
LIGHTING		0.0001	0.0001	NS	0.0001
FRL*LIGHTING		NS	NS	NS	NS

[a-c] Means within a column with unlike superscript differ significantly ($P < 0.01$)
[1]= Feed restriction
[2] = Fasting metabolic rate
[3] = Respiratory quotient

#2

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