FACTORS INFLUENCING ENERGY METABOLISM IN BROILERS AND PULLETS

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NOMENCLATURE

BPW	Buffer peptone water
DEXA	Dual-energy x-ray absorptiometry
E	Electrolyzed water
GI	Gastrointestinal tract
$HOCl^-$	Hypochlorus acid
NEW	Non electrolyzed water
OCl^-	Hypoclorite ion
ORP	Oxidation reduction potential
VM	Virginiamycin
SA	Standard addition
ME	Metabolic energy

CHAPTER I

INTRODUCTION

The poultry industry is one of the fastest growing industries and in the United States poultry production has grown rapidly over the last 50 years. The world's poultry industry has grown from primarily small backyard activities is in the early 1900s, when chickens were generally fed by-products without formal feeding and management systems. The transformation of poultry production from backyard activities to integrated industries has been possible by the combined efforts of genetics, nutritionist, corporations, and government officials (Etches, 1998). At present only six weeks are required to produce a 2 kg commercial broiler, however in 1950, between 12 and 14 weeks were required to produce the 2 kg chicken. The credit of this achievement goes to the intensive research at multiple levels (Universities, poultry companies, government agencies).

The annual growth rate of poultry meat production has been greater than other species, for example it is double that of pork, 3.4 times that of mutton and chevan, and 6 times that of beef (Taha, 2001). World poultry meat production increased nearly eightfold, from 8.9 to 70.4 million tons from 1961 to 2006. The countries that represent most of this production are the United States of America 24%, China 18.5% and European Union 14% (USDA 2001). Broiler production in the United States has increased from less than 1 billion birds in 1950 to an annual production of 8 billion

broilers produced in 1998 (USDA, 2000). At present the United States broiler production is expected to grow by more than 2% in 2006 to 36.2 billion pounds. Thus so far production in the first quarter of 2006 growth was estimated to be 8.9 billion pounds and is up 2.1 percent from the previous year (Haley, 2006). The increased meat production is a combined result of the increased number of bird's slaughtered (up 3.8%) and an increase in the live weight of processed birds (up 1.5%). In 2006 the average weight at slaughter was recorded to be 5.46 pounds, which is 2.1% higher than 2005. The slight decline in broiler production during the first half of 2007 is likely due to the combined effects of increased feed cost and a lower broiler products price (Haley, 2006).

POULTRY MEAT CONSUMPTION IN THE U.S.

The average annual per capita chicken consumption of a typical American is 80 lb and represents 42.4% of total meat consumption (American-meat-institute fact sheet, 2003). This per capita consumption level has increased from just 50 lbs in 1950. The increase in the annual per capita poultry consumption and the decrease in beef (since 1999) consumption may be the result of consumer preferences (Pimentel and Pimentel, 2003). Preferences of consumers tend to evolve over time. Today's consumers are more health conscious and have busier schedules. The lower percentage of fat in poultry meat and easy to cook products appears to suit today's consumer preferences. Additionally, the higher demand for poultry meat may be due to its lower cost compared to beef and pork, as consumer has a tendency to choose greater quantities of lower priced goods (Haley, 2006).

POULTRY TRADE

The United States exported 5.5 billion pounds of poultry meat in 2003, which was 2 percent more than the 2002 level. During early 2006, the United States was the largest exporter of US broiler meat to Russia (283 million pounds) and Mexico. The demand of China and Hong Kong ranked third among the major importers while the Caribbean islands were the fifth largest export market for U.S. broiler products, (Haley 2006). The United States broiler industry has major challenges, as other major broiler exporting countries like Brazil are increasing their competition, (Taha, 2001). In 2005 the broiler trade was hampered due to Hurricane Katrina and it was 444 million pounds (9%) less than the 2004 level (Haley, 2006). The Avian Influenza ("bird flu") also contributed to falling demand for poultry meat in 2005 and 2006. It is necessary for the United States poultry companies to efficiently adjust to a complex array of economic and social pressure.

POINTS OF CONCERN IN POULTRY INDUSTRY

1. Negative concerns related to use of growth promoting antibiotic, such as antibiotic resistant microorganisms and antibiotic residue in poultry products.
2. Production of lean poultry meat as consumer prefer is more vigilant to calorie intake
3. Production of high producing pullets.

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CHAPTER II

REVIEW OF LITERATURE

The combined efforts of genetics, nutrition and management have resulted in markedly increased weight gain and improved feed conversion ratio (FCR). However, this elevated performance potential is impacted by environmental factors that cause the bird to waste energy and nutrients. Factors impacting ME and nutrient loss include microbial alterations in the gastrointestinal flora. Historically, these have been partially countered by the use of growth promoting antibiotics to minimize such alterations. Such approaches have come under critism as the public preference for birds reared under more drug free systems is desired.

EFFECTS OF GASTROINTESTINAL MICROFLORA

All poultry classes, reared in production environments, have a gastrointestinal microflora that is highly dependent upon the environment. These microorganisms (MCO) comprise an integral part of the gastrointestinal tract of all livestock and are present in the small intestine of poultry within 24 hours post hatching (Naqi et al, 1970). Microbial effects can be both beneficial (vitamin synthesis, toxin destruction) and detrimental (toxin production, infection, nutrient destruction, energy wasting). Ravindran et al. (1984) and Apajalahti et al. (2004) reported that gut microflora decrease nutrient absorption by

increasing gastrointestinal wall thickness, rate of ingesta passage and by increasing the competition between host and MCO for dietary nutrients. These negative points can be quite costly for poultry producers. Coates (1976) suggested that digestive tract microorganisms have net detrimental effects on the host and germfree chicks have superior metabolic efficiency than commercial chicks for energy (12.1%) and nitrogen retention (9.9%). These results indicate that the desirable microbial functions (B vitamin synthesis, nitrogen recovery, and amylase) are considerably offset by the microbes' negative attributes.

The wastage consequences are likely to arise from a combination of direct catabolic actions by the microbes, an inflammation mediated absorption barrier and an enhanced basal metabolic rate (BMR) for the host. Ford and Coates (1971) reported that the presence of MCO in the gastro-intestinal tract causes inflammation and impair nutrient absorption. Intestinal mucosa is the most rapidly regenerating tissue in the body (LeBlond and Walker, 1956) and it consumes significant nutrients for its regeneration. Maintenance of greater intestinal mass, due to microbial interactions, would not only result in greater nutrient oxidation by the intestines but also provide a greater absorption barrier for ingested nutrients. In the case of inorganic compounds, the apparent inverse relationship between absorption extent and intestinal thickness may be a direct cause and effect, while the case for the organic compounds may be due to a combination of thickness and microbial-host oxidation.

Findings for the germ-free models include decreased lamina porpria and reduced mucosal surface area (Gordon and Bruckner-Kardoss, 1961b; Vogt et al., 1985) as well as reduced lymphoid tissue (Gordon and Wostmann, 1960). These conditions are favorable

for sparing nutrients and energy. Gordon and Bruckner-Kardoss (1961a) reported that the penicillin mediated suppression in lamina propria created an environment similar to germ free chicks. The impact of stress must not be ignored, as under stressful conditions the bird's ability for immunological resistance may be reduced (McAllister et al., 1979).

BENEFICIAL EFFECTS OF GROWTH PROMOTING ANTIBIOTICS

Growth promoting antibiotics fed at subtherapeutic levels have long been recognized to improve weight gain and efficiency of feed conversion by reducing the gastrointestinal tract microflora in poultry (Bunyan et al, 1977). Coates et al (1963) reported that germfree chickens grow faster and more efficiently than do conventionally fed chickens and that feed efficiencies achieved by conventional chickens fed subtherapeutic antibiotics are very close to germfree chickens. Several mechanisms have been proposed in the literature that explains the growth promoting effect of antibiotics. Mechanisms such as efficiency of nutrient absorption because of thinner gastrointestinal epithelium (Boyd and Edward; 1967), sparring of nutrients due to reduced competition between host and MCO, reduction in sub clinical infection and less growth depressing metabolites produced by microorganism (Barnes et al 1978; Eyssen et al, 1963 and Huhtanen et al, 1965) have been proposed Virginiamycin is one of the widely used growth promoting antibiotics in the poultry industry and its effects include intestinal thinning, reduced microbial nutrient catabolism and a lowered host basal metabolic rate. Belay and Teeter (1994) reported that broilers consuming Virginiamycin (VM), fortified rations produce less heat at maintenance and consume less oxygen per calorie of metabolizable energy consumed.

Henry et al, (1987) reported that VM reduced intestinal tract mass to a greater degree than bambermycin, oxytetracycline and Zn bacitracin. Several studies in the literature indicated increased nutrient and energy sparing, protein retention and mineral absorption due to ration fortification with Virginiamycin. Even though Virginiamycin had no significant effect on body weight gain and feed intake, but it improved feed efficiency, fat and dry matter retention (Bartov, 1992). Canale (1983) reported that Virginiamycin improved ileal crude protein and energy digestibility by 1.5 and 6.1%, respectively, and hence improved the utilization of digestible crude protein and energy by 0.5 and 1.7%, respectively. Beneficial effects of Virginiamycin have also been noted in mineral absorption. Ravindran et al. (1984) observed improved absorption and retention of P, Ca, Mg, Cu, Fe, Zn and Mn.

BACTERIAL RESISTANCE TO ANTIBIOTICS

Prolonged use of antibiotics in animal feeds as growth promoters fed at subtherapeutic levels potentially leads to the development of bacterial resistant when the same antibiotic is given to both humans and animals. Concerns have been expressed by such organizations as the FDA, USDA and WHO. Long term use of these dual fed antibiotics has created a reservoir of resistant bacteria in the animal kingdom and has the potential to spread to human beings (Wegener, 1999). In 1984 the Center for Disease Control and Prevention (CDC) published a report about the emergence of antibiotic resistant strains of *Salmonella*, *Campylobacter* and *Ecoli*. Nawaz et al (2001) reported quinupristin resistant bacteria in patients who had never been exposed to it. Even though quinupristin is not used in livestock feed, microorganisms are becoming resistant to it. The development of cross antibiotic resistance among microorganisms poses a potential

threat to human health. Wegener (1999) reported the increased incidents of *campylobacte*r infections resistant to quinolones in Minnesota from 1992 to 1998. According to the CDC (Centers for disease control and prevention) there has also been an increase in resistant *Salmonella typhimurium*, responsible for major cause of illness in humans and animals, in Europe from 0.6% in 1979 to 34% in1996 (Glynn et al, 1998). This strain of *Salmonella* is resistant to ampicillin, chloraphenicol, streptomycin, sulfonamides, and tetracyclin. The multidrug resistant *Salmonella typhimurium* is a significant cause of illness in human and animals in the UK.

Smith et al (1999) reported an increased incidence of quinolone resistant *Campylobacter jejuni* infection in Minnesota from 1992-1998 due to the high prevalence of *C.jejuni* in retail chicken products domestically produced. The DNA fingerprints *from C.jejuni* (Chicken products) were identical to that of quinolone resistant *C.jejuni* from infected human patients and infected patients were found to have a longer duration of diarrhea than patients who are sensitive to quinolone treatment. Emergence of antibiotic resistant bacteria can be seriously vulnerable to immunocompromised patients. Furthermore, the emergence of Vancomycin resistant *Enterococcus faecium* infection has been linked to the use of glycoprotein in animal feeds (Wegener, 1999). Increased meat trade and traveling by individuals may aggravate this problem to the international level. As a result, there is considerable debate on the use of antibiotics in livestock industry. The rising concern of bacterial resistance with daily antibiotics treatment is causing the industry to take steps towards antibiotic replacement. In Europe, growth promoting antibiotics have already been banned, and the U.S. may soon follow suit.

ELECTROLYZED WATER

Electrolyzed water (EW) is possibly an emerging alternative to treat bacterial and viral infections in poultry (Kim et al, 2005). It is produced by electrolyzing a diluted NaCl solution that is separated by a diaphragm into basic and acidic fraction in an electrolyzed generator (RPA biotech[TM1]). The basic section has a cathode that produces an alkaline electrolyzed water (pH around 11) with an oxidation-reduction potential (ORP) of approximately 80mV. The acidic section has an anode that produces an acidic electrolyzed water (pH of 2.6) with an ORP of approximately 1100mV and a free chlorine range between 10-100mg/L (Kim et al, 2005). The 10% fraction (Free chlorine 10mg/L) is the one with antimicrobial activity (Mauriana, 2006).

A number of studies have been conducted indicating a bactericidal property of electrolyzed water in the meat, egg and livestock industries. In the meat industry *Listeria monocytogenes*, *E. coli* (O157:H7) and *Salmonella enteritidis* are the leading pathogens in ready-to-eat meat, raw ground beef and eggs respectively (Mauriana, 2006). These pathogens are responsible for various food borne illnesses in the consumer. Mauriana (2006) compared the efficacy of (EW) with buffer peptone water (BPW) and non-electrolyzed water (NEW). This study revealed the 6 log reduction of pathogen (*E.Coli, Listeria monocytogenes* and *Salmonella enteritidis*) as compared to BPW and NEW. He suggested that electrolyzed water possibly disrupts the cell wall of pathogens leading to intracellular leakage and ultimately death of cells. In the egg industry *Salmonella* infection is a major problem to consumer groups due to potential consumption of contaminated eggs. Bailka et al (2004) reported that eggs treated with electrolyzed water showed a 10 log reduction in *Salmonella enteridis* and *E. Coli* number by more than 2.1

[1] RPA biotech[TM], 1408 Pawnee Dr, Las Vegas, NV 89109, Unites States.

and 2.3 times compared to commercial detergent that showed a log reduction of 1.7 and 2.0 for *Salmonella enteridis* and *E. Coli* respectively.

A study by Kim et al. (2005) showed that electrolyzed water was just as effective as chlorinated water for removing *Campylobacter jejuni* from poultry carcasses. In other work (Venkitanarayanan et al 1999) electrolyzed water reduced the *Escherichia Coli* and *Listeria monocytogenes* number by more than 5.0 log /cm^2 as compared to deionized water and act as more effective method for inactivating the food born pathogens. The inactivation of food related pathogens may be due to Oxidation Reduction potential of electrolyzed water produced by hypochlorous acid (HOCl) and hypochlorite ions (OCl^-) (Kim et al., 2000; Len et al., 2000).

The shelf life of electrolyzed water is affected by storage conditions, pH and chlorine loss (Len, 2002). The rate of chlorine loss increase by 5 fold with agitation, but it is not significantly affected by light (Len, 2002). Also, electrolyzed water compared to other bactericidal compounds like ozone, chlorine oxide, hydrogen peroxide and sodium chlorite does not have problems of quality deterioration, chemical residue, discoloration and high cost (Kim et al, 2005). These works suggest that electrolyzed water is effective in killing harmful microorganisms that may contaminate poultry carcasses and may also be effective in destroying harmful microbes in the digestive tract of poultry. As such, electrolyzed water may be a replacement for growth promoting antibiotics. This would potentially alleviate concerns over microbes strains that have become immune to the commonly given antibiotics as well as the residual antibiotic effect on human beings consuming poultry products.

BROILER COMPOSITION FROM PRODUCER VIEW

The principle goal of poultry producers is to consistently meet consumer demand for poultry products in a profitable manner. The methods that poultry companies use to assess profit can have an impact upon bird composition and may place the consumer and industry at odds. For example, companies ascertaining production efficiency as live weight and FCR may experience motivation to excessively fatten birds as lipid adds body mass and to a point improves FCR. Such live mass is distributed throughout the bird's body as edible portions and offal. Fat passed on to the consumer potentially creates profit for the poultry companies as elevated weight, while lipid in the offal (skin, mesenteric, abdominal and gizzard fat) has less value. Lipid composition of the offal is a concern as elevated lipid content reflects dietary calories lost as the birds consumed energy to create it. Lipid mass passed to the consumer, mostly as skin, potentially leads to reduced consumer acceptance and loss as the skin may be discarded. However selling of skinless parts to the consumer also leads to loss of energy and monetary inputs to the producer. Consumption of products with elevated lipid increases consumer calorie consumption and contributes to obesity concerns.

Feed industries frequently increase the energy density of the diet to get a better FCR (McKinney and Teeter, 2004). Unfortunately this may also lead to elevated fat deposition, especially around the small intestine and abdominal region (R.D.King, 2001). Fat deposition around the small intestine and gizzard is a direct loss to the producer because the small intestine is considered inedible in most countries and is removed from the carcass along with the fat during the dressing of the bird. Consequently the energy consumed by birds to synthesize this fat has less value. On the other hand abdominal fat

is not a loss for the poultry producer as consumers pay for the whole bird even though the consumer does not necessarily want it when purchasing whole carcasses. Excess fat in birds affect the percentage product yield, moisture uptake during chilling, and cut up yield by lowering the percentage lean tissue (Plavnik and Yahav, 1998). Fat contains more energy than protein tissue (protein 5.65 kcal/g, fat 9.4 kcal/g). However lean tissue contains 75% water (Sklan and Noy, 2004) and though the efficiency of protein accretion (kp=0.67) is lower than lipid accretion efficiency (kf=0.88), both protein and lipid gain improve FCR.

BROILER COMPOSITION FROM CONSUMER VIEW

Excess fat in poultry is not only a problem for the producer but also to the consumer. The amount of fat deposited in the broiler has been of interest to consumer groups to avoid excess fat consumption. The average annual per capita chicken consumption of a typical American is 80 lb and represents 42.4% of total meat consumption (American meat institute fact sheet, 2003). This per capita consumption level has increased from 50 lbs in 1950 to over 80 lbs today. As a result any nutrition and management impact upon the calorie content of poultry products would potentially have a significant impact upon annual energy consumption by consumers.

Increased calorie consumption has been related to a number of health problems such as obesity, hypertension, coronary heart disease, stroke, sleep apnea, osteoarthritis, deep vein thrombosis and diabetes. According to a NHANES III survey from 1988-1994, over half of American adults are overweight, and obesity is the second leading cause of preventable death in United States after smoking (MMWR, 1997). Improved vigilance of all food products is needed to assist in lowering caloric consumption. Consumers need a

readily available supply of palatable protein with acceptable lipid level. At the time of slaughter, the broiler carcass has an average weight of 1763 g (live weight = 2,440 g) with 11.71% fat, 8% protein, 63.9% moisture, and 2.49% ash (Pesti and Bakalli, 1997). The following example depicts the impact what a 1% reduction in carcass fat would have upon the consumer calorie consumption:

> Per capita poultry meat consumption averages 80 lbs (36,320g) and is equivalent to 39,978 kcal of energy from fat (11.71 % fat /100 × 36,320g = 4,253g (fat) × 9.4kcal/g = 39,978 kcal) per year (Haley, 2006). If the fat content of the broiler carcass is reduced by 1%, it would save 3,413 kcal consumption per year as fat (1/100 × 36,320 g= 363 g × 9.4 kcal/g = 3,413 kcal). If we decrease the fat by 1% it means we are adding 1% more lean. The increase in energy intake from 1% more lean will be 508 kcal (1/100 ×36320g= 363.20g (protein) ×5.6 kcal/g × 0.25 = 508.48 kcal). An average American is served 3,800 kcal/day (Haley, 2006). Of these 3,800 kcal, 1100 kcal are lost as spoilage, plate waste, and other losses. The net energy per capita consumption by an average American per day = 2,700 kcal/day. The typical American annually consumes 985,500 kcal of energy (2700 kcal/day × 365 days). The net energy intake of an average American is 982087 kcal/year (Haley, 2006). This reduces annual calorie intake by 2905 kcal (3413 kcal (fat) – 508 kcal (protein)). Over a 10 year period this would reduce average body fat by 7 pounds if the whole carcass were consumed.

Today the consumer is more concerned about specific carcass parts as breast, legs, drumsticks, and wings instead of the entire carcass. As a result, it is more important to know the composition of the individual body part with and without skin. The logic

behind this is to know not only the composition of individual parts but also the variation of fat deposition between the different parts. These however; are impacted by maturity, body weight, nutrition and management. Ideally the consumer would make better decisions and purchase specific parts according to their nutrition needs. Such could create a marketing edge for poultry companies if composition were defined.

Methodologies are needed to easily estimate fat content of poultry tissues. Further information is needed regarding the interactive impact of nutrition and management upon bird composition. The ideal composition would be one that satisfy growth and FCR concerns of the commercial industry and the health concerns of the consumers.

PULLET COMPOSITION AND GROWTH DYNAMICS

Egg production in the pullet is a complex process involving many factors that stimulate the pullet to lay eggs. Such factors as environment (Light and temperature), nutrition (Carbohydrate, fat and protein), and physiology (Hormones and enzymes, Lewis et al, 1994). During the pullet phase the chick transforms from about 45g into a bird ready for light stimulation and sexual maturity weighing about 2,160 grams. Pullet age at onset of lay varies from 18 to 22 weeks and reaches a peak at about 90% of production 6 to 8 weeks latter. Followings peak production, egg output then gradually declines to about 65% after 12 months of laying cycle (Jacob, 1998).

Breeder flocks experience significant variation in hen house production which may be partially explained by body weight and composition. Considerable variation exists in field composition for pullet weights. Pullet field data typically exhibits considerable variability in the target weight (4.3 lb to 5.8 lb) and the body composition ranges approximately 995 to 1,425 grams of lean tissue at 15 weeks and about 1,450 to

2,125 at 20 weeks of age. In contrast the lipid ranges from 30 g to 190 at 15 weeks and 125 to 330g at 20 weeks.

During the 15 – 25 week time frame it has been assumed that energy not utilized for tissue gain and was used for sexual development and/or activity, (Cobb Breeder Manual, 2003). The added energy has been associated with improved egg production in those situations and indicates that the window for achieving good egg production involves many factors.

FEED RESTRICTION

Feed restriction during pullet rearing is important in order to develop the pullet's full reproductive potential (Sykes, 1972). Modern broiler strains have the potential to grow fast and attain an adult size quickly, which leads to increase in maintenance requirement and decrease in egg quality and quantity (Bartov et al, 1998). Feed restriction is usually practiced, such as reducing the feed amount by 70 to 80 %, diluting the diet with fiber, by feeding low protein diets, by feeding specific amino acids deficient diet and by restricting feeding time to a set pattern (every day and skip a day) (Pym, 1969). Out of all these methods restriction by feeding time is widely practiced in the layer industry. Feed restriction by feeding time may be as small amounts of feed fed every day (ED). Alternatively, a feed restriction method used in the US is every-other-day (EOD; or 'skip-a-day') feeding. Every day feed restriction reduces the uniformity of the flock due to competition for feed. However in order to minimize this problem EOD, broiler breeders are provided twice their daily allowance of feed every other day. This system has been reported to result in greater flock uniformity than every day feeding (Bartov et

al, 1998). However EOD does not improve flock uniformity completely (Bartov et al, 1998).

SUBSTRATE METABOLISM

Substrate metabolism (carbohydrate, lipid and protein) may play an important role in the number of eggs laid during a production cycle. In layers, the time of restricted feeding is very critical on total egg production during feed restriction. In cases where layers are not able to mobilize fat depots, they begin mobilizing protein which could have a negative impact on future egg production (Mbugua et al, 1985).

Caloin (2004) reported that the animal body consists of both metabolic and structural compartment. Lipid and protein present in the metabolic compartments are of physiological importance (enzymes, structural compartments and neuromuscular messengers) and is presumably related to the total body lipid and total body protein content. However lipid is the main energy source and protein is mostly important for vital process like enzymes, structural and messengers. At high adiposity level there is sparing of protein for energy production. When breeders have marginal lipid stores, metabolism shifts from lipid to protein.

Caloin (2004) described starvation in three phases. During the first phases the animal derives energy from the diet consumed with the length of this phase depending upon the individual and diet. During second phase, animals use lipid for the energy and the length of this phase depend upon the adiposity of the animal. In phase 2, Nitrogen excretion is almost constant and with protein sparing dependent upon the adiposity. In last phase animals metabolism switches to protein catabolism for energy production and that leads to increase nitrogen excretion. This phase is generally very short and leads to

death because of shutting down of vital body processes. This work by Caloin (2004) shows that adiposity spares the protein metabolism for energy production.

The respiratory quotient (ratio of CO2 production to O2 consumption) is a metabolic tool that may be used to determine the kind of substrate being metabolized at a specific time. Lusk (1928) estimated the substrate oxidation by using indirect calorimetry. Latter Brouwer (1958) developed the equation for estimation of heat production. If the RQ determined is 1, 0.7 or 0.8 then birds are metabolizing carbohydrate, fat and protein, respectively (Chwalibog et al, 1992).

Research conducted by Koh and Macleod (1999) indicated the effect of different feeding levels (adlib, 75%, 50%, 25% and 0% of adlib) on RQ and heat production in the broiler during a circadian period. Data shows that RQ decline with the decrease in feeding level. The RQ of ad libitum birds and fasted group remained constant throughout the study. This means that ad libitum and starvation birds metabolizing carbohydrate and lipid respectively. However the RQ of the other three groups (75%, 50% and 25% of ad libitum) started to decrease and reached a constant level. The birds that were fed 25% of ad libitum reached constant level of RQ faster and earlier followed by 50% and 75% group. Overall data shows that bird's metabolism shifts from carbohydrate to lipid, but broiler would be expected to have considerably more lipid reserves than the limit fed breeder.

A study conducted in our laboratory suggests that RQ value varies within 8 hours of starvation in broilers. Since the birds were metabolizing carbohydrate at the start of the fasting period, the RQ determined was close to 1. As the fasting period advanced, RQ continued to drop until it leveled at 0.7, which is an indication that the birds shifted

substrate metabolism to fat. We subsequently observed a rise in RQ to about 0.8 as the fasting period progressed suggesting that the bird's metabolism shifted to protein. So the question is posed; does the amount of lipid store influence bird RQ? Further when feeding management push some flocks into protein catabolism and does this impact egg production. Since bird metabolism shifts from carbohydrate to lipid and then to protein. Does lipid availability for mobilization impact egg production? If lipid is not available then bird metabolism shifts to protein. Would elevated protein catabolism impact egg production?

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CHAPTER III

ELECTROLYZED WATER EFFECTS ON MALE BROILER PERFORMANCE THROUGH 42 DAYS OF AGE

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ABSTRACT: A study was conducted utilizing Cobb X Cobb male broilers to examine the influence of water antimicrobial treatment termed electrolyzed water (E) upon broiler performance from hatch through 42 days of age. The study contrasted 3 treatments with a non medicated ration and drinking water combination serving as a negative control (C, trt.1); non medicated ration with E fortification (22 ppm of Cl^{-2}, trt 2); conventional ration including 20 ppm. Virginiamycin^{TM} (V, 20 ppm, trt 3) coupled with untreated drinking water. Results were tallied on days 21, 35 and 42 as cumulative performance and interval performance quantified during the starter (1-21d), grower (21-35d) and finisher periods (35-42 d). Upon study completion, no treatment differences were detected for cumulative feed and water consumption, feed efficiency, percent mortality or water to feed consumption ratio, while the V group exhibited the highest live weight ($P<0.01$). During the starter and grower periods, no other variable differences were detected among the three treatments upon study completion ($P > 0.1$). During the finisher period, birds consuming V exhibited improved feed consumption, gain to feed ratio, and percent mortality ($P<0.01$) while the E group showed a reduced performance compared to the negative control. These results suggest that electrolyzed water has little effect on

broiler performance through the starter - grower periods and reduced performance at 22 ppm during the finisher period. Reasons for the reduced finisher period performance are unclear. Overall, the response to V was less than anticipated. Additional E levels warrant investigation as the negative finisher phase data suggests that microbial action occurred in vivo. Perhaps a dose less than 22 ppm would be more efficient.

INTRODUCTION

Poultry classes reared in production environments have a gastrointestinal microflora that is highly dependent upon the environment and comprises an integral part of the bird environment interface. Gastrointestinal microorganisms (MCO) are present within the small intestine of poultry within 24 hours post hatch (Naqi et al, 1990). Microbial effects can be both beneficial (vitamin synthesis, toxin destruction etc.) and detrimental (toxin production, infection, nutrient destruction, energy wasting). This later point can be quite costly for poultry producers. Ravindran et al. (1984) and Apajalahti et al. (2004) reported that gut microflora decrease nutrient absorption by increasing gastrointestinal wall thickness, rate of digesta passage, and by elevating competition between the host and MCO for dietary nutrients. Ford and Coates (1971) also reported that the presence of MCO in the gastro-intestinal tract causes inflammation and impaired nutrient absorption. Microbial mediated inflammation would be expected to enhance host basal metabolic rate (BMR) and lead to energy and nutrient wastage.

Growth promoting antibiotics fed at subtherapeutic levels have long been recognized to improve weight gain and efficiency of feed conversion in poultry (Bunyan et al, 1977). Several mechanisms have been used to explain the growth promoting effect

of antibiotics. Efficiency of nutrient absorption due to thinner GI epithelium (Eyssen and Desomer, 1963; Boyd and Edward, 1967), sparing of nutrients due to reduced competition between the host and MCO (Monson et al, 1954), and reduction in subclinical infection and growth depressing metabolites produced by microorganism (Barnes et al, 1978; Eyssen et al, 1963) are the beneficial effects of antibiotics. Indeed, Coates et al (1963) reported that germfree chickens grow faster and more efficiently than do conventionally reared birds. Broilers fed subtherapeutic levels of antibiotic exhibit performance that is close to the germfree bird.

Belay and Teeter (1994) reported that broilers consuming Virginiamycin (VM) fortified rations produce less heat at maintenance and consume less oxygen per calorie of metabolizable energy consumed. Their data suggests improvement on net ration energy due to VM. Henry et al (1987) reported that VM reduced intestinal tract mass to a greater degree than bambermycin, oxytetracycline and Zn bacitracin. Canale (1983) reported that VM improved ileal crude protein and energy digestibility by 1.5 and 6.1% respectively and the utilization of digested crude protein and energy by 0.5 and 1.7%, respectively. Beneficial effects of VM have also been noted for mineral absorption as Ravindran et al (1984) observed elevated absorption and retention for P, Ca, Mg, Cu, Fe, Zn and Mn.

The use of subtherapeutic levels of antibiotics in animal feeds has been criticized for their potential to lead to the development of bacterial resistance (Glynn, 1998). Antibiotic inclusion in animal feeds has been an issue of debate for such organizations as the FDA, USDA and WHO. At present, the development of cross antibiotic resistances among microorganisms potentially poses a threat to human health. In 1984, the Centers for Disease Control and Prevention (CDC) published a report concerning the emergence

of antibiotic resistant strains of *Salmonella, Campylobacter and E. coli* (Wegener, 1999). Nawaz et al. (2001) observed quinupristin resistant bacteria in patients who had previously never been exposed to quinupristin. Even though quinupristin is not used in livestock feed, microorganisms have developed resistance to it and fuels concern over general growth promoter application. Wegener (1999) reported increased incidents of campylobacter infections resistant to quinolones in Minnesota from 1992 to 1998. According to the CDC there has been an increase in resistant *Salmonella* sp. in European animals from 0.6% in 1979 to 34% in 1996, (Glynn et al, 1998). *Listeria monocytogenes*, *Ecoli* (O157:H7) and *Salmonella enteritidis* are the leading pathogens in ready-to-eat meat, raw ground beef, and eggs, respectively (Mauriana, 2006).

The rising concern of bacterial resistance with daily exposure to antibiotics encourages the industry to move towards their elimination. Such has occurred in Europe with the banning of growth promoting antibiotics in 1999. Electrolyzed water may offer an alternative for countering MCO effects in poultry without the real or perceived risks of including antibiotics in animal feeds. Recent research (Mauriana, 2006) compared the efficacy of Electrolyzed water (EW) with buffered peptone water (BPW) and non-electrolyzed water. This study revealed a 6 log reduction of pathogens (*E.Coli, L. monocytogenes* and *S. enteritidis*) as compared to BPW and non-electrolyzed water. Results suggested that electrolyzed water disrupts cell walls leading to intracellular leakage and ultimately cell death. Additional work by Kim et al. (2005) indicated that electrolyzed water had similar efficacy to water chlorination for removing *Campylobacter jejuni* from poultry carcasses. In other work (Venkitanarayanan et al, 1999), electrolyzed water reduced the *E Coli* and *L. monocytogenes* number by more than

5.0 log /cm^2 as compared to deionized water. This work, along with that reported by RPA Biotech, suggests that electrolyzed water may be effective in destroying harmful microbes in the digestive tract of poultry. As a result, the use of electrolyzed water may alleviate concerns regarding the emergence of microbial resistant strains that are immune to antibiotics as well as residual antibiotic effects on human beings consuming poultry products. The purpose of this study reported herein was to determine if electrolyzed water might be used as an alternative to growth promoting antibiotics.

MATERIAL AND METHODS

At experiment initiation, 450 day old male Cobb (500) broilers chicks were received from a commercial hatchery. Upon arrival at Oklahoma State University, birds were weighed and randomly assigned to one of the three treatments (Table 1): 1). Negative control as non medicated feed and water; 2). Electrolyzed water (22 ppm) with non medicated feed; 3). Positive control with medicated feed (virginiamycin 20 ppm) and non medicated drinking water. Treatments were examined with 25 birds per replicate and 6 replicates per treatment (Table 1). Replicate groups were housed in floor pens using old litter top-dressed with fresh wood shavings. Chicks were given a starter diet containing 22.1% CP and 3,053 Kcal/kg ME (Table 2). All birds were provided feed and water for ad libitum consumption throughout the trial.

PEN PREPARATION

Floor pens were prepared for experiment initiation by top dressing used poultry litter with fresh wood shavings. Birds were maintained in the floor pens to 6 days before chick placement in order to expose chicks to a microbial load presumed to be present in the old poultry litter. Each pen contained two hanging feeders, drinker with nipples and

hanging gas brooder for temperature control. A 60 watt bulb provided light. The heating and ventilation system strictly followed the Cobb recommendation for brooding. Since it was winter time (November), the extra ventilation openings of the house were converted to winter management.

DIET

The corn soybean meal based ration composition is displayed in Table 2. Birds were reared on a typical broiler diet containing 22.1% CP and 3,050 Kcal/kg ME during the starter phase (hatch through 21d) provided as a mash. On day 21 starter consumption and live weight were determined and the treatment groups switched to the pelleted grower feed. The pelleted grower ration contained 19.8% CP and 3,131 Kcal/kg ME through day 42.

WATER

Drinking water was supplied to each pen via a closed pressured system to eliminate spillage and minimize evaporation and provide water flow. Each pen was supplied with water from reservoirs with tightly fitted lids. A small hole in the reservoir lid allowed protrusion of the electrical cord and water hose from a submersible pump. Drinking water was pumped from the reservoir assigned to each pen by submersible pump. Tap water was used for the C and V treatments while tap water fortified with electrolyzed water was used for the E treatment. Water was weighed and added to the barrel weekly during the starter period and twice per week during the grower and finisher periods. Electrolyzed water was delivered to the poultry farm with an initial 225 ppm concentration. Drinking water for the E treatment was diluted to 22 ppm (9 parts of tap water**:** 1 part of electrolyzed water) before adding to the drinking water reservoir.

Electrolyzed water concentration was provided by SanAquel[2] LLC™ and tested once per week for free chlorine as well as total chlorine (Table 3).

BIRD MANAGEMENT

Chicks were reared according to the Cobb Vantress broiler management guide. Birds were allowed to consume feed and water ad libitum to mimic industry standards for broiler rearing. The lighting program utilized was 23L: 1D. At 21, 35 and 42 days of age, Birds were weighed by pen and weight gain estimated as the difference between final and initial weights. Feed consumption was estimated as a difference between the weights of feed offered and refused. Water consumption was estimated by difference of water offered and reservoir weigh back. Gain efficiency was determined as the ratio between body weight gain and feed consumption. Pens were checked multiple times daily for mortality, feed availability, ambient temperature and nipple height. Dead birds were immediately weighed with the dead bird weight, pen number and date recorded. Feed conversion ratios were adjusted for mortality by adding the weights of dead birds to the live bird mass.

STATISTICAL ANALYSIS

The data was analyzed for each interval (Starter, Grower and Finisher) and also as cumulative values over the experiment duration. Statistical analysis software (SAS) was used for estimation of treatment effects on the growth performance. When a significant F statistic was detected ($P < 0.05$), treatments were separated using Least square means. Differences among treatment means was identified using Least significant differences at $P< 0.05$ or as otherwise reported.

[2] SanAquel LLC, 502 Industrial road, Bristow, OK 74010

RESULTS AND DISCUSSION

STARTER (1 TO 21 DAY)

The mean feed consumption, body weight, water consumption, gain to feed ratios, mortality and water to feed ratio data did not differ ($P>0.1$) among the three treatments (Table: 4). A numerically higher feed and water consumption was noted for V ($P>0.05$) followed by C and E. Control birds exhibited numerically higher body weight and gain/feed (feed efficiency $P>0.8$) ratio followed by E and V. The percentage mortality was numerically higher for V ($P>0.1$) followed by E and C. The water/feed ratio was numerically higher for E ($P>0.05$) and lowest for V.

GROWER (DAY 21 TO 35 DAY)

As is depicted in Table 4, all variables monitered were not different ($P>0.1$) among the three treatments. However, V had numerically higher feed consumption and weight gain. The E group exhibited a numerically lower mean feed consumption and weight gain. Virginiamycin birds had 0% mortality while C and E birds had 0.6% mortality (Table 5). Similarly, no differences were noted for the cumulative starter and grower period values (Table 6).

FINISHER (DAY35 TO 42 DAY)

Treatment impacts were noted on mean feed consumption, gain to feed ratio and percent mortality ($P<0.05$) (Table 4). Mean feed consumption was higher for C (1,528g) followed by E (1,378 g) and V (1,358 g). Birds consuming V fortified ration exhibited improved gain to feed ratio at 0.56 over that observed for C and E at 0.48. Improved feed efficiency for V birds was detected with or without adjustment for mortality. The

percentage mortality was zero for V and C group with both less ($P < 0.05$) than E (Table 5).

The study was successfully conducted as judged by overall bird performance. Birds consuming V achieved a live weight of 2,771 g with a FCR of 1.79 (Table 6). Data reported by Cobb for the growth curve and FCR is 2,848 g at 1.75 FCR respectively. Such data was collected under near ideal conditions. Results from this study were just 2.7% off the genetic potential for live weight and 2.2% for FCR.

Response to V yielded birds that were heavier at 2,771 g vs E birds at 2,579 with C being similar (Table 6). Though the final FCR was not significant for V, it was 6 points better than C. Generally field data yields approximately 3 points of feed conversion for V under field production facilities. Such field conditions generally follow week for sterilization with litter being composted in broiler houses, this study allowed just 6 bird free days with no litter composting and should have created a higher MCO level. Overall mortality for the study averaged 4.9%. Typical field flocks will average about 3.5% mortality for this age of bird. The slight increase in study mortality over field conditions may be a reflection of an elevated microbial challenge. Additionally, as the study was conducted in winter months some impact of the environment cannot be ruled out. Bird response to V is generally better in the summer (Belay and Teeter, 1994).

Treatment responses for the starter, grower, finisher and cumulative data were generally well correlated. No treatment impact was noted in the starter and grower periods. Generally response to V is significant. Bird mortality normally benefits from V, while in this study the starter period V had numerically elevated mortality. However increased mortality for V birds was associated with numerically lowered feed efficiencies

for starter birds by 5 points. Adjusted feed efficiency for mortality closed but did not eliminate the gap. In the finisher period, V birds had better feed efficiency followed by C and E. However, this study shows E had elevated morality in the finisher period. The V group birds consumed significantly less feed in the finisher period. While water consumption was not impacted among treatment groups, the C group had numerically higher water consumption by 0.87 %. The water to average weight ratio was not significant among three treatments (Table 5 &7), however, it was highly significant among the different age groups ($P<0.01$). The water to live weight ratio decreased with bird age (Figure 1) and the plot shows that as the age advances birds consume less water per unit live weight. The water to feed ratio decreased with bird live weight (Figure 2) indicating that as the live weight increases bird consume less water per unit of feed consumed.

This study did not detect treatment differences for water to feed and water to weight ratios among treatments; however, throughout the study E birds had a numerically higher value for both ratios. This may be related to a higher ion concentration making electrolyzed water more salty and thereby stimulating E birds to consume more water. In the finisher period, E birds fell behind C and V. The poor performance of E birds may be related to the microbiocidal action of electrolyzed water or some unknown effects of its higher concentration of free chlorine and ions like disturbance of acid base balance due to higher Cl^- concentration.

CONCLUSION

In summary, the study reported herein suggests that electrolyzed water has no significant effect on broiler performance during the starter and grower phases. All three treatment groups had essentially the same performance during starter and grower phase. But in the finisher phase, the birds on electrolyzed water fell behind the other two treatments. Virginiamycin bird performance was better in the finisher phase which may be due to thinning of intestine wall that further leads to more net nutrient absorption as compared to the other two groups. Further study is needed to examine lower E concentrations.

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TABLE 1. Treatments, replicates (reps) and number of birds

Treatment	Treatment Type	Replicates	Birds/Rep	Total
1	Negative control (no electrolyzed water)	6	25	150
2	Electrolyzed water mixture (22 ppm)	6	25	150
3	Positive control, daily virginiamycin (20 ppm)	6	25	150

TABLE 2: Composition of diets used for broiler throughout the experiment

	Age interval (days) and Treatments[1]			
	0 to 21		21 to 42	
Ingredient, %	E and C	V	E and C	V
Corn	58.3	58.3	64.529	64.53
Soybean meal (48 % CP)	34.56	34.56	28.21	28.21
Soybean oil	2.83	2.83	2.93	2.93
Dicalcium phosphate	1.87	1.87	1.98	1.98
Limestone	1.18	1.18	0.92	0.92
NaCl	0.35	0.35	0.29	0.29
Roche Vitamin Premix[2]	0.2	0.2	0.2	0.2
$NaHCO_3$	0.24	0.24	0.32	0.32
DL-Methionine	0.21	0.21	0.22	0.22
Huber trace mineral[3]	0.09	0.09	0.09	0.09
Lysine HCl	0.06	0.06	0.157	0.157
Selenium 600 premix	0.04	0.04	0.04	0.04
Threonine	0.02	0.02	0.05	0.05
Ethoxyquin	0.01	0.01	0.012	0.012
Choline Chloride	0.01	0.01	0	0
Copper Sulfate	0	0	0.002	0.002
L-Arginine	0.03	0.03	0.05	0.05
Sacox-60® (Salinomycin)	0.05	0.05	0.05	0.05
Stafac-20® (Virginiamycin)	0.00	0.05	0.00	0.05
Calculated Analysis				
Me_n (kcal/kg)	3053	3053	3,131	3,131
CP, %	22.1	22.1	19.8	19.8
Arg	1.38	1.38	1.30	1.30
Lys	1.12	1.12	1.14	1.14
Met	0.51	0.51	0.52	0.52
TSAA	0.83	0.83	0.88	0.88
Ca	0.90	0.90	0.80	0.80
P, available	0.44	0.44	0.40	0.40

Treatments: C = Control; E = Electrolyzed water; V = Virginiamycin; 2Supplied per kilogram of diet: vitamin A, 10,141 IU (retinyl acetate); cholecalciferol, 3,086 IU; vitamin E, 23.92 IU (dl-□-tocopheryl acetate); menadione, 2.87 mg; thiamine, 2.20 mg; riboflavin, 7.72 mg; niacin, 60.30 mg; d-pantothenic acid, 12.46 mg; pyridoxine, 3.75 mg; vitamin B12, 0.017 mg; folic acid, 1.066 mg; d-biotin, 0.127 mg; 3Supplied per kilogram of diet: Ca,160 mg; Zn, 100 mg; Mn, 120 mg; Fe,75 mg; Cu, 10 mg; I, 2.5 mg

TABLE 3. Mean total and free chlorine of electrolyzed water during the trial

Days of study	Free Chlorine mg/L	Total Chlorine mg/L
Initial	225	260
4	200	225
16	225	215
23	200	220
30	205	210
37	200	210
Mean ± SD	209.17 ± 12.4	223.33 ± 18.9

TABLE 4. Treatment effects on bird feed and water consumption, weight gain, gain to feed ratio and mortality adjusted gain to feed ratio during starter, grower and finisher intervals

Treatment	Feed (g)	Water (g)	Gain (g)	Gain/feed	Gain/feed#
Starter					
C	1222[a]	2656[a]	873[a]	0.72[a]	0.72[a]
E	1198[a]	2635[a]	849[a]	0.71[a]	0.71[a]
V	1254[a]	2563[a]	835[a]	0.67[a]	0.69[a]
P-value	0.147	0.586	0.134	0.116	0.463
Grower					
C	1974[a]	3985[a]	1154[a]	0.59[a]	0.61[a]
E	1841[a]	3997[a]	1069[a]	0.58[a]	0.61[a]
V	2014[a]	3846[a]	1179[a]	0.59[a]	0.61[a]
P-value	0.089	0.400	0.123	0.989	0.935
Finisher					
C	1528[a]	2330[a]	729[a]	0.478[a]	0.44[a]
E	1378[b]	2221[a]	661[a]	0.476[a]	0.43[a]
V	1358[b]	2282[a]	758[a]	0.558[b]	0.52[b]
P-value	0.03*	0.457	0.175	0.007*	0.004

C: Control; E: Electrolyzed water; V: Virginiamycin; g: gram; * Significant different between treatments;
Adjusted for mortality = [(Gain + (Dead weight - Initial weight))/ feed consumption];
Values obtained by SAS from ANOVA table;
ab: means is a column with unlike superscripts differ ($p<0.05$)

TABLE 5. Treatment effects on bird FCR, percentage mortality, water to feed ratio and water to weight ratio during starter, grower and finisher intervals

Treatment	FCR	Mort%	Water/feed	Water/weight
Starter				
C	1.40[a]	2.6[a]	2.1[a]	5.8[a]
E	1.39[a]	2.7[a]	2.2[a]	5.9[a]
V	1.42[a]	5.3[a]	2.0[a]	5.8[a]
P-value	0.721	0.231	0.229	0.843
Grower				
C	1.72[a]	0.6[a]	2.0[a]	2.7[a]
E	1.73[a]	0.6[a]	2.2[a]	2.9[a]
V	1.71[a]	0.0[a]	1.9[a]	2.7[a]
P-value	0.97	0.616	0.133	0.192
Finisher				
C	2.09[a]	0.0[a]	1.5[a]	0.97[a]
E	2.12[a]	2.0[b]	1.6[a]	0.98[a]
V	1.8[b]	0.0[a]	1.7[a]	0.95[a]
P-value	0.01*	0.044*	0.119	0.58

C: Control; E: Electrolyzed water; V: Virginiamycin; g: gram; * Significant different between treatments; Mort%= Mortality percentage; ab means is a column with unlike superscripts differ ($p<0.05$); Values obtained by SAS from ANOVA table.

TABLE 6. Treatment effects on bird feed and water consumption, weight gain, gain to feed ratio and mortality adjusted gain to feed ratio during cumulative starter, grower and finisher intervals

Treatment	Feed (g)	Water (g)	Live Weight (g)	Gain/feed	Gain/feed#
Starter					
C	1227[a]	2656[a]	873[a]	0.72[a]	0.72[a]
E	1198[a]	2635[a]	849[a]	0.71[a]	0.71[a]
V	1254[a]	2563[a]	835[a]	0.67[a]	0.69[a]
P-value	0.147	0.586	0.134	0.116	0.463
Grower					
C	3205[a]	6660[a]	2027[a]	0.63[a]	0.65[a]
E	3048[ab]	6651[a]	1919[a]	0.63[a]	0.65[a]
V	3268[ac]	6410[a]	2013[a]	0.62[a]	0.64[a]
P-value	0.091	0.257	0.105	0.697	0.578
Finisher					
C	4733[a]	8991[a]	2757[a]	0.58[a]	0.58[a]
E	4523[a]	9070[a]	2579[b]	0.57[a]	0.58[a]
V	4626[a]	8691[a]	2771[a]	0.60[a]	0.59[a]
P-value	0.444	0.251	0.006*	0.363	0.476

C=Control; E=Electrolyzed water; V=Virginiamycin; g=gram; * Significant different between treatments; # adjusted for mortality = [(Cumulative Live weight + Dead weight)/ Cumulative feed consumption]; abc means is a column with unlike superscripts differ ($p<0.05$) Values obtained by SAS from ANOVA table.

TABLE 7. Treatment effects on bird FCR, percentage mortality, water to feed ratio and water to weight ratio during cumulative starter, grower and finisher intervals

Treatments	FCR	Mort%	Water/feed	Water/weight
Starter				
C	1.40[a]	2.6[a]	2.17[a]	5.8[a]
E	1.41[a]	2.7[a]	2.20[a]	5.9[a]
V	1.50[a]	5.3[a]	2.04[a]	5.8[a]
P-value	0.1	0.23	0.22	0.84
Grower				
C	1.58[a]	3.3[a]	2.07[a]	6.8[ab]
E	1.59[a]	3.3[a]	2.19[ab]	7.1[a]
V	1.62[a]	5.3[a]	1.96[ac]	6.6[b]
P-value	0.7	0.46	0.08	0.09
Finisher				
C	1.71[a]	3.3[a]	1.90[a]	6.3[a]
E	1.75[a]	6.0[a]	2.01[a]	6.7[b]
V	1.67[a]	5.3[a]	1.88[a]	6.1[a]
P-value	0.4	0.50	0.16	<0.05

C=Control; E=Electrolyzed water; V=Virginiamycin; g=gram; * Significant different between treatments; # adjusted for mortality = [(Cumulative Live weight + Dead weight)/ Cumulative feed consumption]; ab means is a column with unlike superscripts differ ($p<0.05$); Values obtained by SAS from ANOVA table.

Water to body weight ratio (C) = 7.62308 – 0.00429 × body weight + $6.329647E^{-7}$ × Body $weight^2$ (R^2=0.99)
Water to body weight ratio (E) = 7.72647 – 0.00436 × body weight + $6.091762E^{-7}$ × Body $weight^2$ (R^2=0.98)
Water to body weight ratio (C) = 7.67863 – 0.00451 × body weight + $6.114819E^{-7}$ × Body $weight^2$ (R^2=0.99)

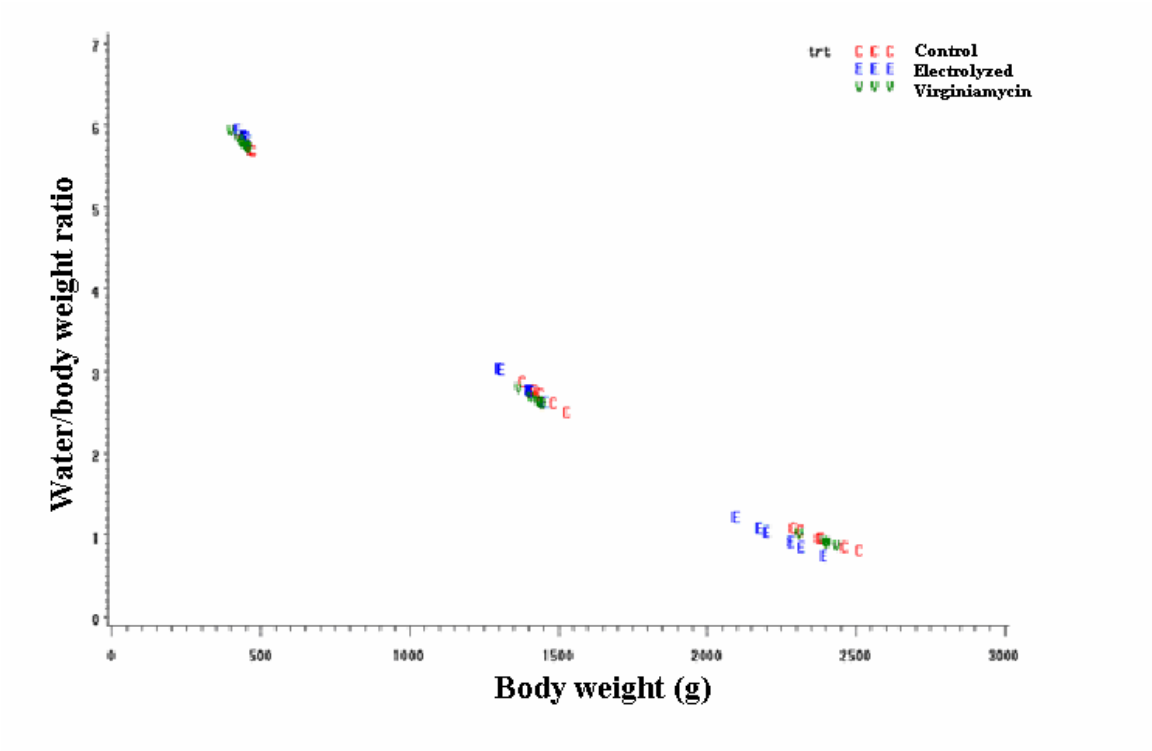

FIGURE 1. Plot of water consumption to body weight ratio versus average body weight (g)

Water to feed ratio = 2.01772 + 0.00022577 × Live weight – 9.58043 × Live weight^2 (g)

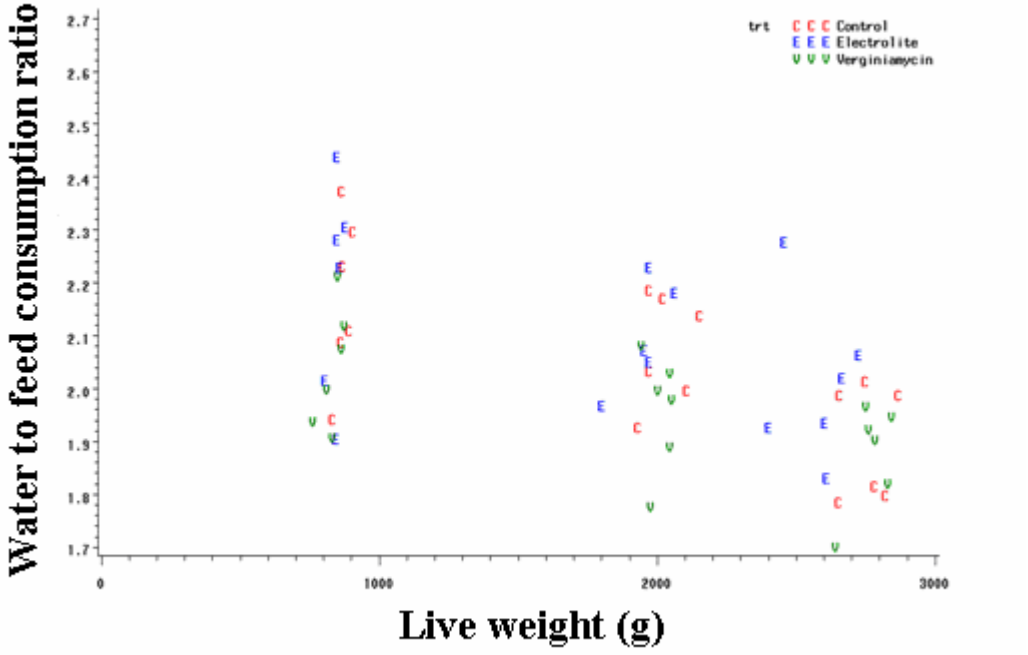

FIGURE 2. Plot of water to feed consumption ratio versus live weight (g)

CHAPTER IV

THE PATTERN OF FAT DEPOSITION IN DIFFERENT BODY PARTS OF THE BROILER THROUGHOUT THE GROWTH CURVE AS INFLUENCED BY NUTRITION AND MANAGEMENT

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ABSTRACT: A study was conducted to estimate broiler carcass fat composition as whole carcass and a carcass portioned into parts through the growth curve to 60 days. The influence of nutrition (energy supplement) and management (pelleted feed) on fat accretion was examined. Broiler composition was estimated by Dual-energy x-ray absorptiometry[3] (DEXA), specific gravity and a modified specific gravity technique. Results were used to propose a bird composition that optimizes calorie conversion to live weight for the industry and health concerns of the consumer. Treatments consisted of mash; mash plus soybean oil (187 kcals ME_n / kg diet DM), and steam pelleted mash fed for 10, 19, 32, 47 and 60 days. The whole defeathered bird, its carcass, and parts were examined. Carcass weight increased ($p< 0.05$) with age, while specific gravity declined quadratically ($p<0.05$) suggesting that as birds mature they become fatter at an increasing rate. Indeed breast specific gravity with and without skin increased as birds aged ($p<0.05$), while breast skin specific gravity declined. The specific gravity of leg with and without skin declined slightly with bird age while specific gravity of leg skin decreased ($p<0.05$). The Specific gravity of abdominal, gizzard and mesenteric tissue declined

[3] Hologic Model QDR 4500A, Hologic Corpoation, Waltham, MA.

($p<0.05$) with age suggesting that an increase in lipid content of these tissues in addition to mass. The specific gravity of gizzard and small intestine without fat remained constant with age; however specific gravity of these parts with fat declined ($p<0.05$) with age. The possibility of using a modified method of Standard additions (SA) was attempted by adding known quantities of saturated fat to the carcass and carcass parts so that the fat content might be estimated from their specific gravity by regression. The percentage of fat in the defeathered bird and carcass estimated by the SA procedure was similar to fat estimated by DEXA through 47 days, however, at 60 days the SA fat was higher ($p<0.01$) than DEXA fat. Consequently DEXA fat was used to calculate the energy in the carcass and gastrointestinal tract. The 2006 broiler consuming diet 1 (Mash) had significantly less energy (0.04 kcal/g and 0.06 kcal/g of carcass) compared to diet 2 (Mash plus soybean oil) and 3 (Mash pelleted and sifted) respectively ($p < 0.05$). The 2006 broiler consuming diet 1 had less energy (0.02 kcal/g of GI tract) in the GI tract compared to diet 2 ($p<0.05$). While 2006 broiler consuming diet 3 has less energy in GI tract (0.03 kcal/g and 0.05 kcal/g of GI tract) compared to diet 1 and 2 respectively. In conclusion, diet 1 carcass had fewer calories both in carcass and GI tract. However diet 2 deposited more calories in carcass and GI tract. Diet 3 deposited more calories in carcass and less in GI tract.

INTRODUCTION

A number of methods have been used to estimate fat percentage such as X-ray densitometry (McKinney and Teeter, 2004), specific gravity, and proximate analysis (Cuthbertson, 1978). The X-ray method is rapid and direct, but it is not as accurate as

proximate analysis. The Proximate analysis is the only direct method but is time consuming and destroys the sample. The specific gravity method is based upon the assumption that the carcass is made of two-components (fat and nonfat). Since the specific gravity of fat is less than the specific gravity of the nonfat components, the larger the proportion of fat the lower is the overall specific gravity of the carcass. This method is more popular for estimating carcass composition in mammals as compared to broilers. Relatively few studies contrast carcass specific gravity with more direct procedures to estimate the carcass composition (Fortin and Chambers, 1980) as air entrapment in the carcass cavity may skew results. Air entrapment was identified by Garrett (1969) and Miles (1976) as a major source of error. Nonetheless, specific gravity has been correlated with body fat ($R^2 = 0.8$) as is similar to Wiernusz et al (2001). The disadvantages might be minimized by measuring the specific gravity of the individual carcass parts such as leg (drumstick plus thigh), wing, breast, skin and GI tract, instead of the entire carcass.

The objective of the study presented herein was to provide an estimation of fat composition of carcass and its parts by specific gravity. Other objectives of this study are to determine the pattern of fat deposition (whole carcass and individual body parts) as influenced by nutrition, management (pelleted feed) and energy supplementation across the broiler growth curve and to propose a bird composition that optimizes calorie conversion to live weight for the industry and health concerns for the consumer.

MATERIAL AND METHODS

BIRD HISTORY

Birds used in this study were taken from an earlier trial that was conducted to evaluate the effective caloric value (ECV) of pelleting (McKinney et al, 2005). The aim of the experiment was also to evaluate dietary nutrients in ratio to ECV. Day old Cobb (500) chicks were obtained from a commercial poultry hatchery. Upon the arrival of chicks at OSU, the birds were wing-banded and allotted by sex to floor pens (3.5 × 2.0 m) with used litter top-dressed with fresh wood shavings. The lighting program followed was 23L:1D and the stocking density was 45 birds per pen. Birds were reared with ad libitum access to feed and water on starter (0-18 d), grower (18-35 d), and finisher (35-60 d) diets (Table 1). Rations were formulated to meet or exceed nutrient recommendations of the Cobb Broiler Nutrition Guide (2003). Treatments were: 1.) Mash; 2.) Mash plus soybean oil (187 kcals ME_n / kg diet; M187); and 3.) Mash steam pelleted and sifted (P). COMPOSITION: Birds were euthanized at five ages: (10, 19, 32, 47 and 60 days) and scanned for composition using dual-energy x-ray absorptiometry (DEXA) as described by McKinney et al. (2005) and frozen till analysis. The birds were thawed overnight at room temperature, scanned with X-ray densitometer to determine composition, weighed in air and water for specific gravity determination and processed by removing head, feet, liver, and gastrointestinal tract. Eviscerated carcasses were again weighed in air and water and then scanned using DEXA. Carcasses were patted with paper towel to remove water and cut into legs (femur-ileum joint), breasts and wings (homeruns-scapula joint). Both right and left breast were separated along the sternum. Each part was weighed in air and water, with and without skin. The gizzard and small intestine were opened and

contents removed. The gizzard and small intestine were weighed in air and water, with and without visceral fat. Since both fat and skin are lighter than water, buoyancy was used for skins, mesentery tissue, gizzard and abdominal fat, by adding a known quantity of weight to the sample. The specific gravity for the samples with density greater than water was calculated as: Specific gravity = Wt in air / (wt in air - wt in water) (Fortin and Chambers, 1981). Measures were made to ± 0.01 grams. For samples with density less than water, specific gravity was estimated as: Sample weight in air/Sample weight in air – (Lead weight in water plus sample – Lead weight in water). Temperature of the emmersia water was maintained at 25°C ± 1°C throughout the weighing procedure to minimize changes in water density. The weighing balance was well protected from all sides to minimize reading fluctuation due to air flow. When an internal standard was examined, a saturated hydrogenated vegetable oil (Crisco ^{TM}) was used to make a response curve of specific gravity versus percent added fat. Specific gravity was used for tissues that are heavier than water as breast, leg and wings while buoyancy was used for the tissues with less density than water as fat and skin. Modified method of standard addition was used to estimate fat percentage from specific and buoyancy measures as follows (Scatchard Plot; Ferdinand. W, 1976):

> A known quantity of saturated fat (Crisco) was added to the sample so that the change in specific gravity attributable to fat addition might be determined, creating a negative slope of specific gravity versus percent added fat. Since the density of lean tissue appears to change with age (McKinney, 2005) and the specific gravity is viewed as a 2 pool model, these values were subtracted from the specific gravity of boneless skinless breast for the bird. Then the specific

gravity change was regressed against fat addition and the absolute value of the abscissa intercept used as the lipid estimate for the sample.

STATISTICAL ANALYSIS

Bird served as the experimental unit. Data were analyzed using the General Linear Models of SAS (2000), with probability values of $P < 0.05$ considered significant. When a significant F-statistic was detected, Least square means were used for treatment comparisons (Steel and Torrie, 1980).

RESULTS AND DISCUSSION

Due to a freezer malfunction only a portion of the samples were analyzed. The samples were however, equally dispersed over treatments and bird ages. With these exceptions the study was successfully completed for the samples analyzed. Bird age and dietary treatments were examined for effects on carcass and carcass parts composition. Carcass weight increased ($p< 0.05$) with age while specific gravity declined quadratically ($p<0.05$) suggesting that as birds mature they become fatter (Figure 1). Specific gravity versus live weight reveals quadratic relationships ($R^2 = 0.3$, Figure 2). Results for tissue mass relationships for various poultry tissues (Live weight, carcass, left and right breast with and without skin, left and right leg with and without skin, left and right wings, gizzard with and without fat, small intestine with and without fat, liver, abdominal fat, gizzard fat, mesenteric fat and skins of breast and legs) with age are displayed in the Tables 1 and 2. In all cases weight of the tissues increased with the increase in carcass weight while proportion estimated as % was variable. Relationships of various tissues

weight versus live weight (Figures 3 to 10) and carcass weight (Figures 11 to 18) are displayed. The weights of all the parts increased with live and carcass mass.

The specific gravity of various tissues is shown in Table 3, while relationships between specific gravity and carcass weight of various parts are displayed in Figures 19 to 26. The specific gravity of the carcass, similar to most tissues except boneless skinless meat declined with age. Indeed breast specific gravity with and without skin increased as birds aged, while breast skin specific gravity declined (Figure 19 and 20). Other work in our laboratory (McKinney, 2005) indicated the breast meat dry matter increases with age suggesting that the tissue become denser. The specific gravity of leg with and without skin slightly decreased with bird age while specific gravity of leg skin decreased markedly (Figure 21 and 22).

The Specific gravity of abdominal, gizzard and mesenteric tissue declined with age suggesting that adipocytes of abdominal, gizzard and mesenteric tissue deposit more fat per unit mass with increased bird live weight. (Figure 24, 25 and 26). The specific gravity of gizzard and small intestine without fat remained constant with age in contrast to boneless skinless breast; however specific gravity of these parts with fat declined significantly with age (Figure 24 - 26). Plot of the specific gravity of mesenteric fat versus carcass weight showed a negative slope (Figure 26) indicating increased lipid percentage of mesenteric adipocytes tissue with increasing age. Other fat depots as abdominal and gizzard fat (Figure 24, 25 and 26) also exhibited a decline in specific gravity with age. The diet effect on abdominal fat specific gravity is displayed in Figure 34. The abdominal fat specific gravity of birds fed diet 2 was higher on day 19 than those

fed diet 1 and 3. However birds fed diet 1 had higher abdominal fat specific gravity on day 30, 47 and 60.

Data for providing input for the standard addition (SA) prediction of carcass and carcass tissue lipid content are displayed in Tables 4 and 5. The calculation involved the mathematical addition of 6 levels of saturated fat to the tissue sample and the recalculation of specific gravity for the mixture (Figure 27). Since the purpose of the modified standard addition procedure is to create an internal standard, it is necessary to have a positive response. Also it is apparent that tissue specific gravity is influenced differently by tissues at the various ages. The specific gravity of the boneless skinless breast increased with age (Table 3 & Figure 19); gizzard and small intestine remained constant while most adipose related tissues declined. The skeletal mass comprises over 90% of bird ash, but only 3% of its total mass. Though skeletal mass increases with bird age, its proportion is relatively constant. It was thereby decided to use boneless skinless breast specific gravity as a reference point and compute the difference between breast specific gravity and sample specific gravity with graded amounts of added saturated fat as shown in Figure 28. The positive slope shows the increase in carcass specific gravity with the addition of saturated fat relative to the bird's boneless skinless breast sample. Extrapolating this line to the abscissa provides an estimation of the percentage fat in the sample.

The carcass fat estimation according to the modified standard addition procedure described herein is plotted versus the carcass weight (Figure 29). Data indicates that carcasses are getting fatter with the increased carcass weight. Carcass fat estimation by the modified standard addition procedure was plotted and compared with DEXA fat

estimation and is displayed in Figure 30 and Tables 6 and 7. Note that the two approaches provide similar overall value. When the means are contrasted at 136 ± 55 and 137 ± 20 for the modified standard addition and DEXA procedure at age 32 days, respectively (Table 7).

The fat in the defeathered bird (carcass with head, legs and gastrointestinal tract) was estimated with results plotted against defeathered bird weight (Figure 31).The plot indicated that defeathered birds were getting fatter with the increased defeathered weight At the age of 60, days fat (g) estimated with modified standard addition procedure compared to the DEXA differed for unknown reason but may include entrapped air (Becker et al 1981) as shown in Figure 33.

Composition of live, defeathered bird and carcass was estimated with DEXA and is displayed in the Table 6. Data indicated that protein, fat, ash and water increased with age. The fat percentages related to live and carcass weight estimated by DEXA and standard addition procedure are compared in Table 7 for the different ages. The percentage of fat in the defeathered bird and carcass estimated by the standard addition procedure are similar to fat estimated by DEXA through 47 days, however, at the age of 60 days fat % (Standard addition procedure) is higher ($p<0.05$) than DEXA fat %. The fat in the gastrointestinal tract was calculated by subtracting the carcass fat from the defeathered bird fat (Table 7). In 10 d old birds most of the bird fat is present in the GI tract related to carcass, however in latter ages the proportion of the bird fat in GI tract declined significantly. This decrease in GI tract fat proportion to the total bird fat suggests that as the bird ages the lipid accretion takes places other than GI tract. This makes lipid content portioning important to the consumer. Similarly the proportion of

carcass mass as GI tract is also higher during the early age and later declines with age. However, the fat estimated by the modified standard addition procedure had higher standard deviation, suggesting elevated variability with this procedure. Indeed the specific gravity of a tissue is variable with many factors; in the modified standard procedure our assumption was to consider variability only through fat. In older birds the percentage dry matter of the non lipid tissue also increased and this had an impact on specific gravity. This may potentially be the cause of elevated variability in the modified standard addition procedure fat estimation.

The effect of energy supplementation on the fat content of the defeathered bird, carcass and GI are compared in Table 8 for different ages. The supplementation of energy had a significant impact upon the fat (grams) estimated by DEXA, however at ages 10, 19, 32, and 47 d fat estimated by standard addition procedure did detect an impact due to energy till 60 days. The fat to protein ratios for carcass and gastrointestinal tract are displayed in Table 9, indicating that the fat to protein ratio increased with age. The effect of diet on the fat content of the defeathered bird, carcass and GI tract is displayed in Table 9. The effect of diet and age by diet interaction have significant effect on fat estimated by DEXA procedure, however, modified standard addition procedure did not detect significant effects due to diet. Diet 2 and 3 has the same energy, diet 2 has oil (187 kcal) and diet 3 is in pellet form (management mediated energy addition). There is no significant difference on the carcass and GI fat during ages 10, 19, and 32 d due to diet 2 and 3 according to DEXA procedure, however, at ages 47 and 60 d there is a significant difference ($p < 0.05$) in carcass and GI fat estimated by the DEXA procedure. The fat to protein ratio of carcass and GI estimated by DEXA procedure are significantly different

($p < 0.05$) due to diet, however, this ratio is same for diet 2 and 3 ($P > 0.1$), but fat to protein ratio of carcass and GI due to diet 1 is significantly different ($p<0.05$) from diet 2 and 3. The increase in fat to protein ratios in carcass and gastrointestinal tract are of big concern to consumer and producer, respectively.

The effect of different diets on the calories present in the carcass and GI tract are displayed in the table 10. The calories present in the live bird and carcass of the birds consuming diet 2 and 3 are very close to each other. Data suggests that birds consumed diet 1 have less calories in their carcass compared to diet 2 and 3; however birds consumed diet 2 has more energy in their GI tract than diet 1 and 3. The carcass to GI tract calories ratio along the age is displayed in the Figure 32, indicating that diet 2 and 3 have higher carcass to GI tract energy ratio throughout all the ages, indicating that diet 2 and 3 have significant higher carcass to GI energy ratio compare to diet 1. This demonstrates that management influence upon bird activity impacts carcass composition.

The consumer is most concerned about composition differences impacting calorie consumption. Diet 1 had less carcass calories (2.57 - 2.53=0.04 kcal/g) than the other diets. If we relate this extra amount of energy due to diet 2 and 3 to the annual consumption of broiler meat by an average American, which is 36,320 g (USDA Fact book, 2001), then this value become 1,452.8 kcal. The carcass from diet 1 can lower the annual energy intake of an average American by 1,453 ($0.04 \times 36{,}320 = 1453$ kcal). As today's consumer is conscious of the calorie consumption, the carcass from diet 1 can potentially reduce the consumer annual calorie consumption by 1,453 kcal. However, if we compare the carcass calories of diet 1 and 3, the energy difference becomes even higher, which is 0.06 kcal/ g (2.59 – 2.53 = 0.06 kcal/g) and this energy difference can

lower the annual energy intake of an average American by 2,179 kcal (0.06 × 36,320 = 2,179 kcal).

PRODUCER

The GI tract fat generally becomes a byproduct during bird processing and has less value than other bird components. This occurs as a result of elevated energy in the form of GI tract fat, which is a loss to the producer. The data displayed in Table 10 compares the amount of calories wasted in the GI tract due to different diets modeled using regression equation to 2, 2.5 and 3 kg live weight. The birds fed on diet 3 have the least calories in their gastro intestinal tract and the highest is diet 2. The energy difference due to extra calories in diet 2 comes 21.4 kcal / carcass (714.1 – 692.8 = 21.4 kcal/carcass). According to Haley (2006) around 30.1 billion pound of broiler meat was produced in United States in the year 2006 with an average carcass weight of 5.46 pound, which is equivalent to about 5.51 billion broiler carcasses (30.1 billion/5.46). As a result the total energy wastage during processing of broiler birds in the year 2006 was 118×10^9 kcal of energy ($21.4 \times 5.51 \times 10^9 = 118 \times 10^9$ kcal). When a kg of feed has energy around 3,092 kcal and a bag of feed has energy around 69,017 kcal/bag (3,092 kcal/kg × 22.32kg = 69,017 kcal/bag) and cost of a feed bag is approximately $ 8.78. This energy contributes to 1.71×10^6 bags of feed (118×10^9 kcal/69017 kcal/bag = 1.71×10^6 bags). The annual loss of $ 15.01 million in the United States due to wastage in gut.

CONCLUSION

This study suggests that both nutrition and management have an important impact on the producer and consumer goals. Both the consumer and producer are an important part of the industry. The consumer's preference of less calorie consumption can be satisfied by nutrition (diet 1) through feeding low energy ration. Feeding the low energy ration helps the producer's goal of less wastage of energy in the form of GI tract energy but elevates FCR and days on feed to reach target weights. Such an approach generally reduces producer profitability. The addition of fat to the mash ration elevates GI tract energy and places more energy in the carcass. A portion of the producer profitability is offset by elevated GI wastage. Reducing bird behavior by pelleting feed adds an estimated 187 kcal effective caloric value to the broiler ration (McKinney and Teeter, 2004). This calorie value is manifested in the broiler by elevated carcass calories while the GI calories remained unchanged. It would appear that the best approach may be to feed pelleted ration but at even lower energy contents otherwise the bottom line of the study is that diet 1 can satisfy the concerns of the consumer while diet 3 reflects the best intend of the producer.

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TABLE 1. Weight (g ± SD) of broiler body parts and tissue mass as a percent of carcass at various ages

Body	10 d		19 d		32 d		47 d		60 d	
parts	Weight (g)	%C	Weight (g)	%C	Weight (g)	%C	Weight (g)	%C	Weight (g)	%C
LW	185.7 ± 17		635.6 ± 67		1325.4 ± 140		2285.8 ± 382		3032.1 ± 341	
Carcass	130.8 ± 15		497.5 ± 49		1086.3 ± 120		1947.6 ± 345		2626.1 ± 304	
RBS	10 ± 2.3	7.7	52.5 ± 8	10.6	132.5 ± 23	12.2	258.1 ± 68	13.3	363.2 ± 56	13.8
RBWS	8.5 ± 1.9	6.5	45.7 ± 9	9.1	114.3 ± 21	10.5	231.9 ± 69	11.9	322.1 ± 54	12.3
LBS	10.8 ± 2.3	8.3	54.7 ± 8	11.0	136.0 ± 24	12.5	260.9 ± 47	13.4	379.6 ± 77	14.5
LBWS	9.1 ± 2.2	7.0	45.6 ± 7.8	9.5	117.5 ± 22	10.8	231.1 ± 49	11.9	321.0 ± 54	12.2
RLS	18.7 ± 2.2	14.3	72.1 ± 9.5	14.5	152.2 ± 18	14.0	272.0 ± 48	14.0	160.5 ± 55	13.7
RLWS	16.2 ± 1.9	12.4	61.9 ± 7.7	12.4	134.5 ± 15	12.4	237.6 ± 46	12.2	315.6 ± 56	12.0
LLS	18.9 ± 2.4	14.5	69.3 ± 7.6	14.0	155.0 ± 16	14.3	279.7 ± 53	14.4	371.7 ± 56	14.2
LLWS	16.1 ± 2	12.3	58.2 ± 6.2	11.7	133.7 ± 15	12.3	243.4 ± 49	12.5	324.8 ± 54	12.4
RW	8.2 ± 1	6.3	27.7 ± 2.5	5.6	58.4 ± 6	5.4	95.7 ± 10.3	4.9	120.1 ± 11	4.6
LW	8.2 ± 1	6.7	27.8 ± 3.1	5.6	60.1±5.5	5.5	99.1 ± 12.7	5.1	125.7 ± 13	4.9

Lw: Live weight; RBS: Right breast with skin; RBWS: Right breast without skin; LBS: Left breast with skin; LBWS: Left breast without skin; RLS: Right leg with skin; RLWS: Right leg without skin; LLS: Left leg with skin; LLWS: Left leg without skin; RW: Right wing; LW: Left Wing; d: days; %C: Percentage of carcass weight.

TABLE 2. Weight (g ± SD) of broiler visceral parts and tissue mass as a percent of carcass at various ages

Visceral	10 d		19 d		32 d		47 d		60 d	
parts	Weight (g)	%C	Weight (g)	%C	Weight (g)	%C	Weight (g)	%C	Weight (g)	%C
G	7.2 ± 1.1	5.5	16.8 ± 3.1	3.4	31.4 ± 8	2.9	45.5 ± 11.4	2.3	67.3 ± 14.4	2.7
GWF	6.2 ± 1.0	4.7	13.0 ± 2.1	2.6	19.8 ± 3.1	1.8	24.8 ± 6.0	1.3	31.7 ± 7.3	1.2
SI	7.6 ± 7.8	5.8	21.0 ± 3.5	4.2	33.8 ± 5.9	3.1	45.5 ± 9.3	2.3	63.5 ± 11.1	2.4
SIWF	7 ± 1.3	5.4	18.2 ± 3.4	3.6	27.2 ± 7.6	2.5	29.0 ± 6.7	1.5	34.1 ± 5	3.1
GF	0.8 ± 0.5	0.6	4.0 ± 1.5	0.8	9.7 ± 3	0.9	19.7 ± 5.5	1.0	35.6 ± 11.6	1.4
MF	0.56 ± 0.4	0.4	2.6 ± 1	0.5	7.9 ± 2.6	0.7	16.6 ± 4.4	0.9	29.5 ± 10.4	1.1
AB	1.0 ± 0.4	0.8	5.9 ± 1.8	1.2	15.6 ± 5.5	1.4	33.8 ± 9.7	1.7	64.8 ± 23.5	2.5
Liver	4.8 ± 0.6	3.7	16.0 ± 2.9	3.2	28.2 ± 4	2.6	39.8 ± 5.3	2.0	47.8 ± 10.5	8.2
SRB	1.8 ± 0.5	1.4	8.4 ± 2.7	1.7	18.7 ± 3.3	1.7	29.9 ± 7.2	1.5	43.8 ± 9.2	1.6
SLB	1.9 ± 0.8	1.5	8.6 ± 2.5	2.0	20.1 ± 8.4	1.8	31.9 ± 8.6	1.6	47.7 ± 9.0	1.8
SRL	2.9 ± 0.8	2.2	10.3 ± 2.4	2.1	20.5 ± 4.1	1.9	35.0 ± 5.3	1.8	46.6 ± 6.2	1.8
SLL	3.1 ± 0.7	2.3	10.1 ± 1.6	2.0	21.4 ± 3.1	1.9	36.1 ± 6.5	1.9	47.7 ± 7.5	1.8

G: Gizzard with fat; GWF: Gizzard without fat; SI: Small intestine with fat; SIWF: Small intestine without fat; GF: Gizzard fat; MF: Mesenteric fat; AB: Abdominal fat; SRB: Skin of right breast; SLB: Skin of left breast; SRL: Skin of right leg; SLL: Skin of left leg; d: days; %C: Percentage of carcass weight.

TABLE 3. Specific gravity of various broiler tissues (± SD) at various ages

	Age				
Parts	10 d	19 d	32 d	47 d	60 d
Lw	1.044 ± 0.008	1.046 ± 0.007	1.049 ± 0.005	1.042 ± 0.005	1.035 ± 0.004
Carcass	1.051 ± 0.004	1.053 ± 0.004	1.052 ± 0.005	1.049 ± 0.003	1.043 ± 0.005
RBS	1.052 ± 0.008	1.055 ± 0.009	1.058 ± 0.007	1.062 ± 0.004	1.062 ± 0.004
RBWS	1.060 ± 0.007	1.065 ± 0.007	1.067 ± 0.007	1.070 ± 0.003	1.071 ± 0.002
LBS	1.054 ± 0.009	1.055 ± 0.008	1.058 ± 0.006	1.062 ± 0.004	1.060 ± 0.011
LBWS	1.059 ± 0.008	1.066 ± 0.002	1.067 ± 0.004	1.070 ± 0.003	1.070 ± 0.002
RLS	1.065 ± 0.007	1.062 ± 0.005	1.058 ± 0.005	1.058 ± 0.004	1.050 ± 0.008
RLWS	1.071 ± 0.005	1.068 ± 0.005	1.066 ± 0.005	1.068 ± 0.004	1.062 ± 0.005
LLS	1.061 ± 0.007	1.063 ± 0.003	1.057 ± 0.004	1.054 ± 0.011	1.050 ± 0.006
LLWS	1.069 ± 0.006	1.071 ± 0.005	1.067 ± 0.003	1.067 ± 0.005	1.060 ± 0.006
RW	1.070 ± 0.012	1.073 ± 0.006	1.072 ± 0.008	1.070 ± 0.005	1.063 ± 0.007
LW	1.076 ± 0.009	1.071 ± 0.008	1.071 ± 0.007	1.066 ± 0.005	1.064 ± 0.005
G	1.052 ± 0.007	1.040 ± 0.011	1.022 ± 0.009	1.005 ± 0.002	0.986 ± 0.017
GWF	1.060 ± 0.003	1.063 ± 0.002	1.062 ± 0.002	1.062 ± 0.002	1.052 ± 0.006
SI	1.032 ± 0.011	1.024 ± 0.008	1.015 ± 0.006	1.001 ± 0.007	0.986 ± 0.011
SIWF	1.036 ± 0.015	1.031 ± 0.008	1.026 ± 0.005	1.021 ± 0.004	1.018 ± 0.008
GF	1.022 ± 0.045	0.967 ± 0.024	0.949 ± 0.007	0.943 ±0.006	0.936 ± 0.004
MF	1.023 ± 0.045	0.993 ± 0.019	0.978 ± 0.016	0.964 ± 0.009	0.949 ± 0.009
AB	0.996 ± 0.021	0.961 ± 0.015	0.951 ±0.009	0.938 ± 0.007	0.932 ± 0.003
Liver	1.064 ± 0.003	1.067 ± 0.003	1.067 ± 0.005	1.064 ± 0.005	1.060 ± 0.006
SRB	1.003 ± 0.016	0.996 ± 0.015	0.990 ± 0.009	0.989 ± 0.007	0.979 ± 0.012
SLB	1.003 ± 0.014	0.996 ± 0.011	0.990 ± 0.007	0.977 ± 0.020	0.979 ± 0.010
SRL	1.016 ± 0.023	0.989 ± 0.010	0.977 ± 0.014	0.968 ± 0.013	0.961 ± 0.018
SLL	1.008 ± 0.014	0.987 ± 0.016	0.977 ± 0.014	0.982 ± 0.010	0.953 ± 0.030

RBS: Right breast with skin; RBWS: Right breast without skin; LBS: Left breast with skin; LBWS: Left breast without skin; RLS: Right leg with skin; RLWS: Right leg without skin; LLS: Left leg with skin; LLWS: Left leg without skin; RW: Right wing; LW: Left Wing; G: Gizzard with fat; GWF: Gizzard without fat; SI: Small intestine with fat; SIWF: Small intestine without fat; GF: Gizzard fat; MF: Mesenteric fat; AB: Abdominal fat; SRB: Skin of right breast; SLB: Skin of left breast; SRL: Skin of right leg; SLL: Skin of left leg; d: days; Lw: Live weight.

TABLE 4. Change of specific gravity of broiler body parts with addition of different levels of saturated fat

Parts	DF	Carc	RBS	RBWS	RLS	RLWS	RWS	LWS
Crisco Added (g)								
0	1.044	1.052	1.053	1.063	1.065	1.071	1.070	1.070
210.60	0.977	0.969	0.930	0.929	0.935	0.934	0.929	0.929
238.48	0.974	0.966	0.929	0.929	0.933	0.933	0.929	0.929
310.59	0.966	0.959	0.928	0.928	0.932	0.931	0.928	0.928
381.62	0.961	0.954	0.928	0.927	0.930	0.930	0.827	0.927
445.53	0.957	0.951	0.927	0.927	0.929	0.929	0.927	0.927
516.59	0.954	0.948	0.927	0.926	0.929	0.928	0.927	0.927

DF: Defeather bird; Carc: Carcass; RBS: Right breast with skin; RBWS: Right breast without skin; RLS: Right leg with skin; RLWS: Right leg without skin; RW: Right wing; LW: Left Wing;

TABLE 5. Change of specific gravity of broiler visceral body parts with addition of different levels of saturated fat

Parts	AB	GF	GWF	FG	SRB	SRL	SIF	SIWF	MF	LIVER
Crisco Added (g)										
0	0.996	1.052	1.061	1.022	1.003	1.008	1.033	1.036	1.023	1.023
210.60	0.925	0.928	0.928	0.925	0.926	0.926	0.928	0.928	0.925	0.928
238.48	0.925	0.925	0.928	0.925	0.926	0.926	0.928	0.928	0.925	0.927
310.59	0.925	0.927	0.927	0.925	0.925	0.926	0.927	0.927	0.925	0.927
381.62	0.925	0.927	0.927	0.925	0.925	0.926	0.927	0.927	0.925	0.927
445.53	0.925	0.926	0.926	0.925	0.925	0.926	0.926	0.927	0.925	0.926
516.59	0.925	0.926	0.926	0.925	0.925	0.926	0.926	0.926	0.925	0.926

G: Gizzard with fat; GWF: Gizzard without fat; SI: Small intestine with fat; SIWF: Small intestine without fat; GF: Gizzard fat; MF: Mesenteric fat; AB: Abdominal fat; SRB: Skin of right breast; SRL: Skin of right leg;

TABLE 6. Composition of bird at different ages in grams (± SD) estimated by DEXA.

	Age	10 d	19 d	32 d	47 d	60d
Live Bird	Prot (g)	29.1 ± 3.8	108 ± 5.3	242 ± 3.8	402 ± 9.4	600 ± 7.7
	Fat (g)	14 ± 3.9	66 ± 5.4	180 ± 3.9	355 ± 9.6	628 ± 11
	Ash (g)	3.7 ± 0.6	15.8 ± 0.8	35.8 ± 0.6	59.2 ± 1.4	90 ± 1.2
	Water (g)	145.6 ± 12.5	451.3 ± 17.6	923.9 ± 12.8	1434.9 ± 31.3	2078 ± 26
Defeathered Bird	Prot (g)	27.3 ± 6.5	102.3 ± 9.2	226.7 ± 6.7	374.1 ± 16.3	528.5 ± 8.5
	Fat (g)	13 ± 8.4	61.9 ± 11.9	165 ± 8.6	321.9 ± 21.1	521.5 ± 11
	Ash (g)	3.4 ± 1	14.9 ± 1.4	33.4 ± 1	55.1 ± 2.5	78.3 ± 1.3
	Water (g)	137.1 ± 21	429 ± 29.9	871.3 ± 21.6	1347.6 ± 53	1835 ± 27
Carcass	Prot (g)	17.5 ± 5.4	80.3 ± 7.7	187.3 ± 5.6	330.4 ± 13.7	475.3 ± 7.1
	Fat (g)	7.2 ± 6.7	46.1 ± 9.6	129.5 ± 6.9	272.6 ± 17	447 ± 8.9
	Ash (g)	2 ± 0.8	11.7 ± 1.2	27.7 ± 0.8	48.6 ± 2.1	70 ± 1.1
	Water (g)	101.8 ± 17	350 ± 24	739.6 ± 18	1207.9 ± 44	1662 ± 23

d: Days; Prot: Protein; DEXA: Dual-energy x-ray absorptiometry; Defeathered bird: Live bird without feather; Carcass: Live bird without feather, head, feet and gastrointestinal tract

TABLE 7. Bird fat and fat proportions averaged over energy supplement for processed fraction

Ages	10d	19d	32d	47d	60d	Average
Live weight (g)	186 ± 17	635 ± 67	1325 ± 140	2286 ± 382	3032 ± 341	1428
Carcass weight (g)	131 ± 15	498 ± 49	1086 ± 120	1948 ± 346	2626 ± 305	1200
GI Tract weight (g)	55 ± 3.7	138 ± 29	239 ± 28	338 ± 49	406 ± 66	328
% DF	30 ± 2.5	22 ± 3.5	18 ± 1.5	15 ± 1.8	13 ± 1.7	
% Carc	43 ± 5.4	28 ± 5.6	22 ± 2.2	18 ± 2.5	16 ± 2.2	
Modified Standard addition Procedure						
Defeathered fat[1] (g)	20.6 ± 9.2	80 ± 32.7	162 ± 57	438 ± 150	777 ± 161	282
% DF	11 ± 5.1	12 ± 4.4	12 ± 5.1	19 ±4.7	26 ± 3.8	
Carcass fat[1] (g)	13 ± 8.3	51 ± 19.5	136 ± 55	299 ± 92	572 ± 158	209
% Carcass	10 ± 6	10 ± 3.9	13 ± 5	16 ± 4.2	22 ± 5	
GI fat[1] (g)	8 ± 9.7	29 ± 29	26 ± 35	139 ± 68	205 ± 136	73
% DF[1]	34 ± 33	30 ± 34	16 ± 24	31 ± 8	26 ± 15.3	
% Carc[1]	107 ± 133	76 ± 86	51 ± 153	46 ± 16	41 ± 29	
DEXA Procedure						
Defeathered fat[2] (g)	13 ± 1.8	66 ± 10	173 ± 24	356 ± 82	538 ± 88	229
% DF	7 ± 0.4	10 ± 7	13 ± 4	16 ± 1.1	18 ± 1.0	
Carcass fat[2] (g)	8 ± 1.7	49 ± 7	137 ± 20	308 ± 74	462 ± 75	181
% Carcass	6 ± 0.8	10 ± 0.6	13 ± 5.8	16 ± 1.2	18 ± 0.9	
GI fat[2] (g)	6 ± 0.9	16 ± 3.9	36 ± 8.4	49 ± 22	76 ± 22	49
% DF[2]	45 ± 8.2	25 ± 4.1	21 ± 3.6	14 ± 6.2	14 ± 3.6	
% Carc[2]	85 ± 30.7	33 ± 6.7	27 ± 5.9	16 ± 8	16 ± 4.6	
Age Average	11	46	109	253	433	

[1]: Fat estimated by standard addition procedure; [2]: Fat estimated by dual-energy x-ray absorptiometry (DEXA); GI: Gastrointestinal tract; d: Days; g : Grams; Carc: Carcass; DF: Dfeathered bird (carcass with head, legs and gastrointestinal tract); %DF: Percentage of GI fat from defeathered bird fat ; % Carc[1]: Percentage of GI fat from carcass fat.

TABLE 8: Effect of energy supplementation (187 kcal) on the fat estimated by modified standard addition and DEXA procedure

Age	Supp	Defeathered bird Fat (g)		Carcass Fat (g)		GI fat (g)	
		SA	DEXA	SA	DEXA	SA	DEXA
10 d	None	18.7[a]	11.9[a]	9.7[a]	6.0[a]	9.0[a]	5.9[a]
	Plus	21.4[a]	14.1[a]	12.7[a]	8.2[a]	8.7[a]	5.9[a]
19 d	None	61.6[b]	55.7[b]	48.0[b]	40.8[b]	13.6[b]	14.9[b]
	Plus	84.9[b]	68.1[b]	50.4[b]	51.4[b]	34.5[b]	16.7[b]
32 d	None	139.9[c]	149.2[c]	105.7[c]	115.4[c]	34.2[c]	33.8[c]
	Plus	169.5[c]	180.9[c]	143.5[c]	143.7[d]	26.0[c]	37.2[c]
47 d	None	329.2[d]	253.4[d]	265.3[d]	202.7[e]	64.0[d]	50.7[d]
	Plus	474.8[d]	390.4[e]	308.1[d]	342.5[f]	166.7[d]	47.8[d]
60 d	None	720.6[e]	478.6[f]	592.6[e]	406.3[g]	128.0[e]	72.2[e]
	Plus	802.5[e]	564.5[g]	554.0[e]	487.6[h]	248.4[f]	76.9[e]
P Value	Age	< 0.0001	<0.001	<0.0001	<0.001	<0.0001	<0.0001
	Supp	0.089	0.0005	0.69	<0.001	0.06	0.49
	Age*Supp	0.52	0.0057	0.68	0.003	0.023	0.97

(SA): Standard addition procedure; DEXA: Dual-energy x-ray absorptiometry; d: Days; g : Grams;
DF: Dfeathered bird (carcass with head, legs and gastrointestinal tract); Supp: Supplement energy: None: No supplementation; Plus: Supplementation

TABLE 9. Effect of diet on the fat as measured by modified standard addition and DEXA procedure

Age	Diet	Defeathered bird Fat (g)		Carcass			GI		
				Fat (g)		Fat/protein	Fat (g)		Fat/protein
		SA	DEXA	SA	DEXA	DEXA	SA	DEXA	DEXA
10 d	1	18.7[a]	11.9[a]	9.7[a]	6.0[a]	0.38[a]	9.0[a]	5.9[a]	0.59[a]
	2	26.8[a]	14.0[a]	14.6[a]	8.0[a]	0.42[b]	12.2[a]	6.0[a]	0.61[a]
	3	17.8[a]	14.6[a]	11.5[a]	8.3[a]	0.42[b]	6.3[a]	6.2[a]	0.61[a]
19 d	1	61.6[a]	55.7[a]	48.0[a]	40.8[a]	0.56[a]	13.6[a]	14.9[a]	0.69[a]
	2	66.7[a]	70.5[a]	37.2[a]	51.6[a]	0.59[a]	29.5[a]	18.9[a]	0.73[a]
	3	95.3[a]	69.6[a]	58.0[a]	51.4[a]	0.58[a]	37.3[a]	17.8[a]	0.73[a]
32 d	1	139.9[a]	148.4[a]	105.7[a]	115.4[a]	0.67[a]	34.2[a]	33.0[a]	0.88[a]
	2	158.0[a]	180.7[a]	120.3[a]	144.5[a]	0.71[b]	37.7[a]	36.2[a]	0.93[b]
	3	178.7[a]	182.1[a]	162.0[a]	143.0[a]	0.70[b]	16.6[a]	36.5[a]	0.94[b]
47 d	1	329.2[a]	253.4[a]	265.3[a]	202.7[a]	0.76[a]	63.9[a]	50.7[a]	1.03[a]
	2	563.9[b]	428.0[b]	362.8[a]	358.1[b]	0.88[b]	96.9[a]	70.0[b]	1.26[b]
	3	296.5[a]	328.7[b]	198.6[a]	311.5[b]	0.85[b]	97.9[a]	57.4[a]	1.25[b]
60 d	1	720.6[a]	478.6[a]	593.0[a]	406.3[a]	0.91[a]	128.0[a]	72.2[a]	1.32[a]
	2	801.7[b]	593.0[b]	581.0[a]	506.0[b]	0.97[b]	220.6[b]	87.0[b]	1.47[b]
	3	802.8[ab]	558.0[b]	540.4[a]	478.4[b]	0.95[b]	262.4[b]	81.2[b]	1.45[b]
P Value	Age	<0.0001	< 0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
	Diet	0.21	0.0002	0.92	0.0002	<0.0001	0.17	0.008	<0.0001
	Age*Diet	0.18	0.0023	0.48	0.0067	0.37	0.07	0.14	0.06

SA: Standard addition; DEXA: Dual-energy x-ray absorptiometry; d: Days; g: Grams; Supp: Supplement energy; None: No supplementation; DF: Defeathered bird (carcass with head, legs and gastrointestinal tract); Plus: Supplementation

TABLE 10. Diet effects on modeled energy profile of broiler at three production weights

Diet	Live kcal	Carcass Kcal	Carcass Kcal/g	Gut kcal	Gut kcal/g
Broiler at 2 kg					
1	4635	3926	2.48	537.5	1.93
2	4716	4005	2.52	556.0	1.94
3	4709	4037	2.53	541.4	1.91
2006 broiler (2.5kg)					
1	5897	5042	2.53	692.8	2.06
2	6021	5152	2.57	714.2	2.08
3	6008	5188	2.59	695.5	2.03
Broiler at 3 kg					
1	7158	6159	2.56	848.2	2.15
2	7326	6299	2.60	872.4	2.18
3	7306	6340	2.62	850.0	2.13

GI: Gastro intestinal tract

Diet 1

Live bird energy (Kcal) = - 411.1 + 2.5231 * live weight

Carcass energy (kcal) = -540.96 + 2.2333 * live weight

GI energy (Kcal) = 83.659 + 0.3106 * live weight

Diet 2

Live bird energy (Kcal) = -504 + 2.6101 * live weight

Carcass energy (kcal) = -581.8 + 2.2935 * live weight

GI energy (Kcal) = 77.333 + 0.3166 * live weight

Diet 3

Live bird energy (Kcal) = - 485 + 2.597 * live weight

Carcass energy (kcal) = -571.93 + 2.3041 * live weight

GI energy (Kcal) = 74.754 + 0.3081 * live weight

TABLE 11. Diet effects on the weight profile of broiler at three production weights

Diet	Live weight (g)	Carcass Weight (g)	GI weight (g)
Broiler at 2 kg			
1	2000	1583.2	278
2	2000	1588.0	286
3	2000	1593.8	284
2006 broiler (2.5kg)			
1	2500	1993.4	336
2	2500	2001.4	343
3	2500	2006.5	342
Broiler at 3 kg			
1	3000	2403.7	395
2	3000	2414.8	401
3	3000	2419.3	400

GI: Gastro intestinal tract

Diet 1

Carcass weight (g) = -57.794 + 0.8205 * live weight

GI weight (g) = 45.697 + 0.1161 * live weight

Diet 2

Carcass weight (g) = - 65.838 + 0.8269 * live weight

GI weight (g) = 56.522 + 0.1147 * live weight

Diet 3

Carcass weight (g) = -57.233 + 0.8255 * live weight

GI weight (g) = 50.235 + 0.1167 * live weight

Specific gravity of carcass = -240.69027 + 34.69284*Age + 0.22052*Age^2 (R^2=0.97)

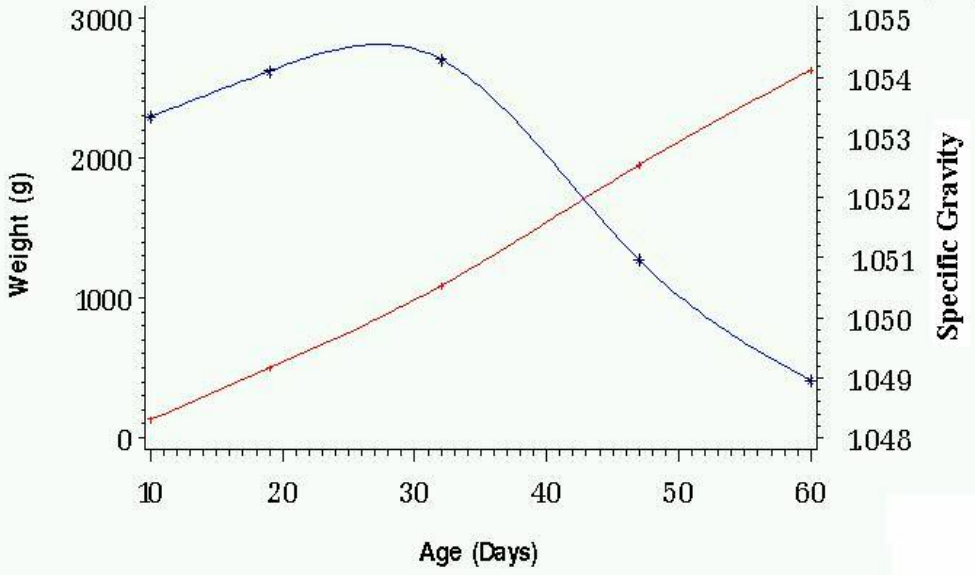

Figure 1. Plot of carcass weight (g) and specific gravity versus age (days)

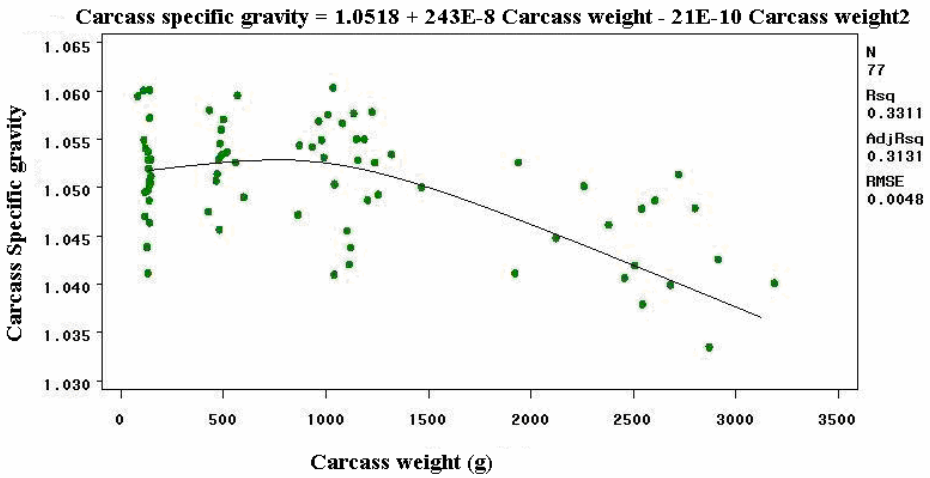

Figure 2. Plot of carcass specific gravity versus carcass weight (g)

Right Breast with skin = -10.08595 + 0.09653*Live weight + 0.864E^{-5}*Live weight^2 (R^2=0.98)
Right Breast without skin = -8.94982 + 0.08246*Live weight + 0.874E^{-5}*Live weight^2 (R^2=0.98)
Skin of Right Breast = -0.91887 + 0.01492*Live weight - 0.014103E^{-5}*Live weight^2 (R^2=0.92)

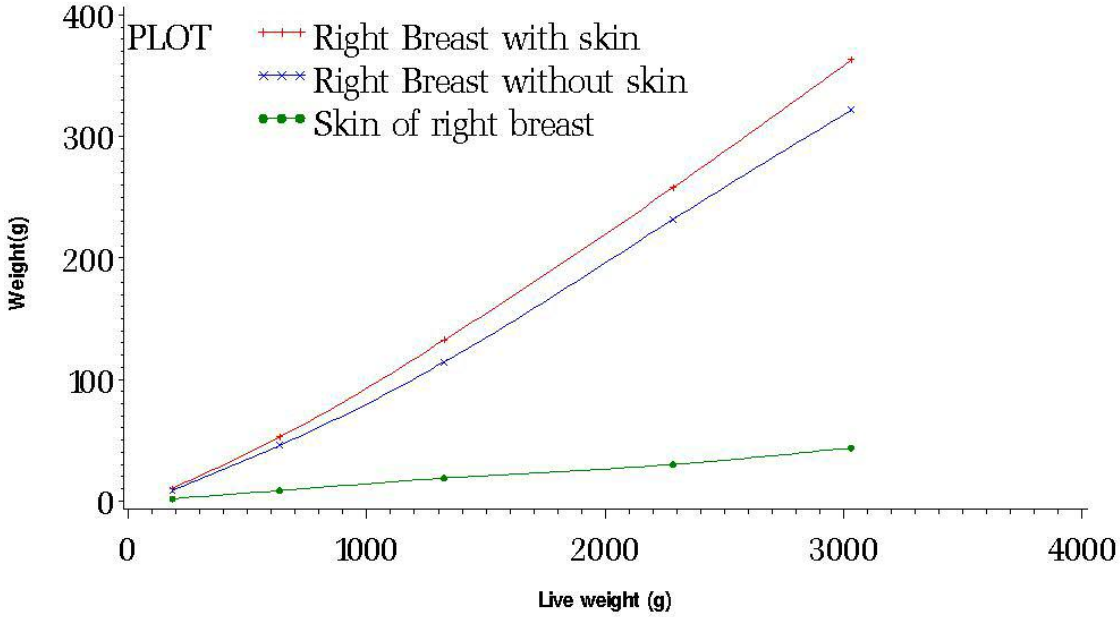

Figure 3. Plot of right breast weight with and without skin versus live weight

Left Breast with skin = -10.73086 + 0.1104*Live weight + $0.855E^{-5}$*Live weight^2 (R^2=0.95)
Left Breast without skin = -9.087 + 0.08601*Live weight + $0.743E^{-5}$*Live weight^2 (R^2=0.98)
Skin of Left Breast = -0.54060 + 0.01449*Live weight + $0.04379682E^{-5}$*Live weight^2 (R^2=0.89)

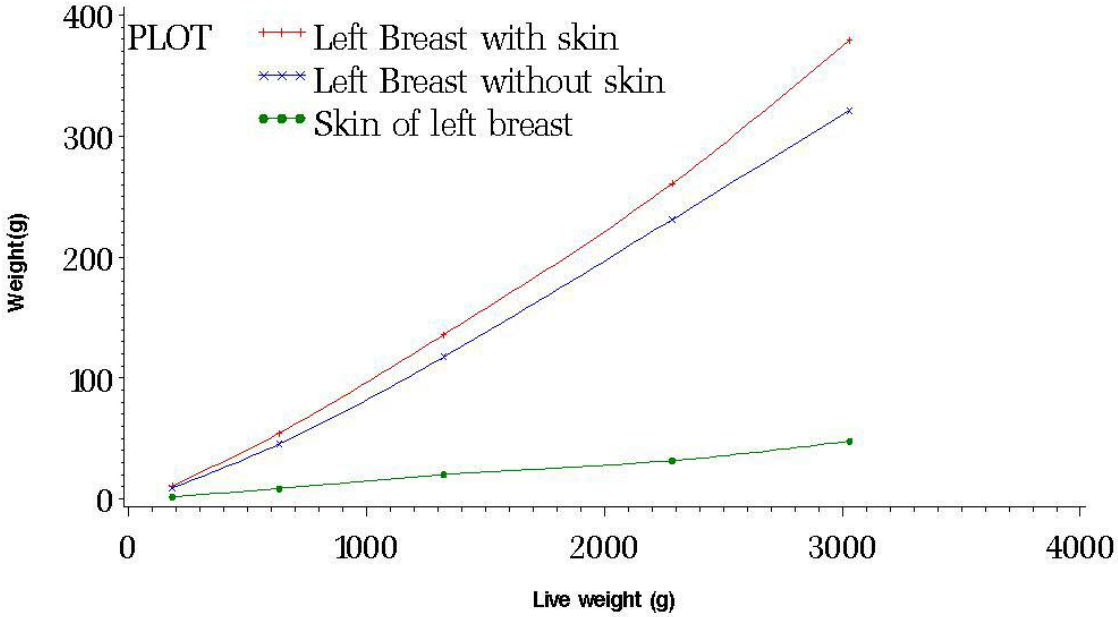

Figure 4. Plot of left breast weight with and without skin versus live weight

Right leg with skin = -1.42196 + 0.11223*Live weight + $0.252E^{-5}$*Live weight^2 (R^2=0.99)
Right leg without skin = -0.64695 + 0.09632*Live weight +$0.295E^{-5}$*Live weight^2 (R^2=0.98)
Skin of Right leg = -0.62998 + 0.01756*Live weight - $0.0768076E^{-5}$*Live weight^2 (R^2=0.95)

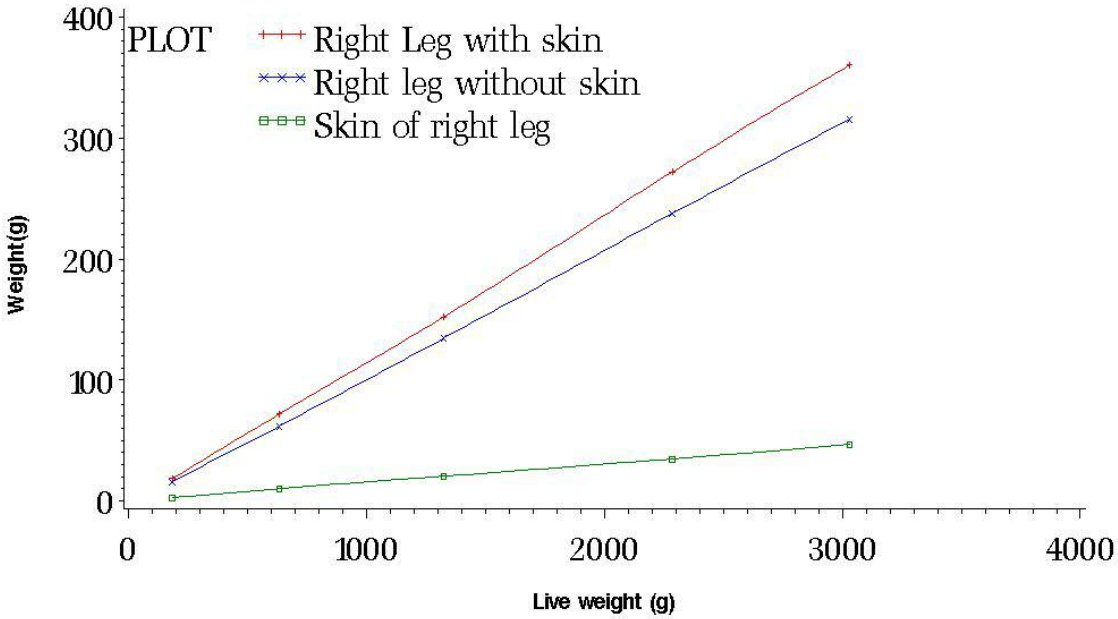

Figure 5. Plot of right leg weight with and without skin versus live weight

Left leg with skin = -2.03884 + 0.11251*Live weight + 0.372E^{-5}*Live weight^2 (R^2=0.99)
Left leg without skin = -1.48222 + 0.09428*Live weight + 0.464E^{-5}*Live weight^2 (R^2=0.99)
Skin of Left leg = -.25874 + 0.01709*Live weight - 0.0470194E^{-5}*Live weight^2 (R^2=0.96)

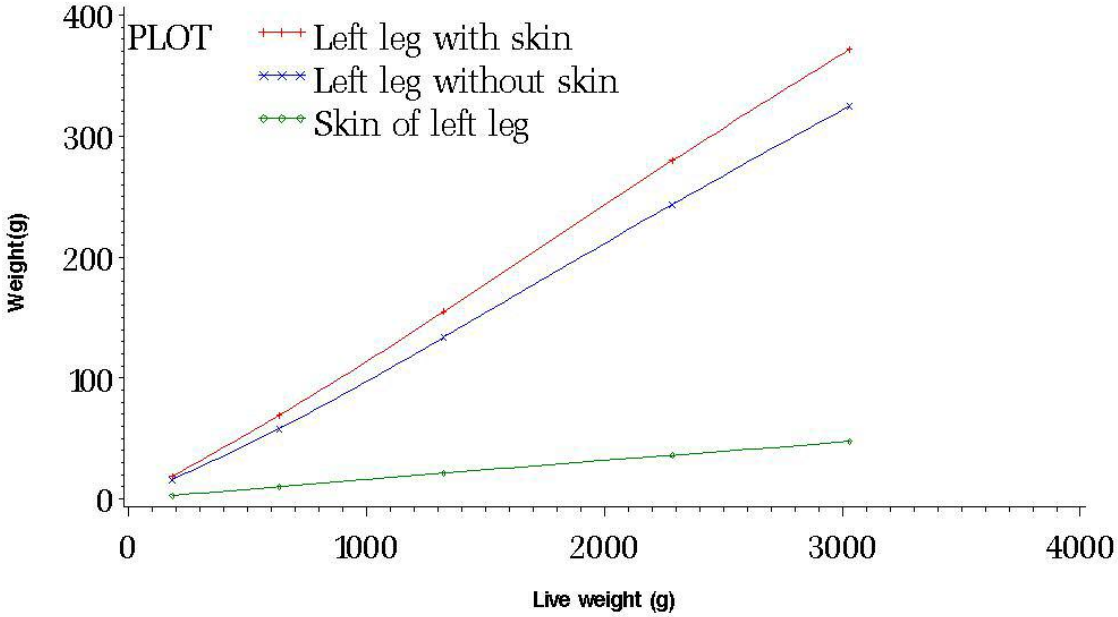

Figure 6. Plot of left leg weight with and without skin versus live weight

Right wing with skin = -1.64803 + 0.05028*Live weight - 0.342E^{-5}*Live weight^2 (R^2=0.98)
Left wing without skin = -1.42589 + 0.04991*Live weight - 0.265E^{-5}*Live weight^2 (R^2=0.99)

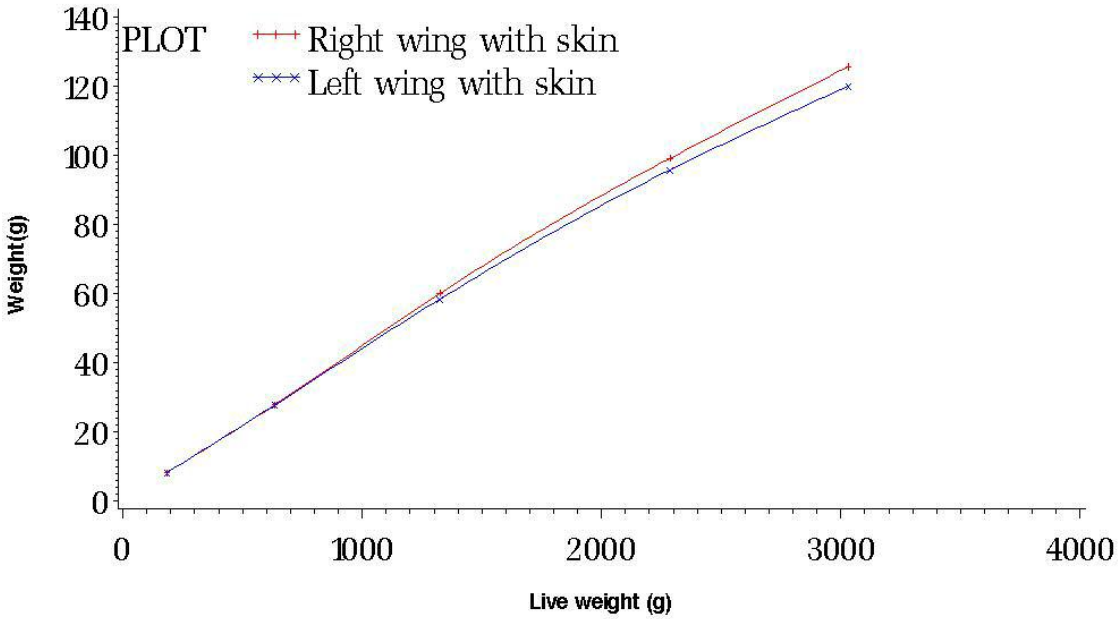

Figure 7. Plot of right and left wing weight with skin versus live weight

Gizzard with fat = 3.40742 + 0.02125*Live weight - $0.0212411E^{-5}$*Live weight^2 (R^2=0.88)
Gizzard without fat = 4.17602 + 0.01369*Live weight - $0.154E^{-5}$*Live weight^2 (R^2=0.85)
Gizzard fat = -0.21582 + 0.00499*Live weight + $0.208E^{-5}$*Live weight^2 (R^2=0.85)

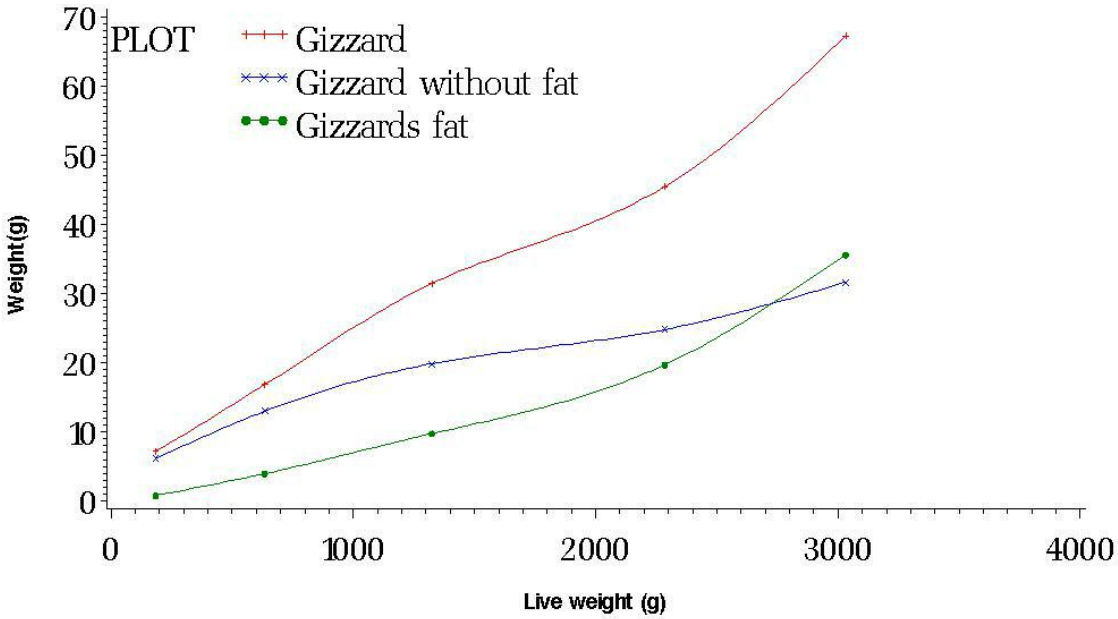

Figure 8. Plot of gizzard weight with and without fat versus live weight

Small intestine with fat = 3.83545 + 0.02492*Live weight - 0.178E^{-5}*Live weight^2 (R^2=0.93)
Small intestine without fat = 4.08035 + 0.02189*Live weightE^{-5} - 0.384*Live weight^2 (R^2=0.81)
Mesenteric fat = -0.69074 + 0.00471*Live weight + 0.158E^{-5}*Live weight^2 (R^2=0.83)

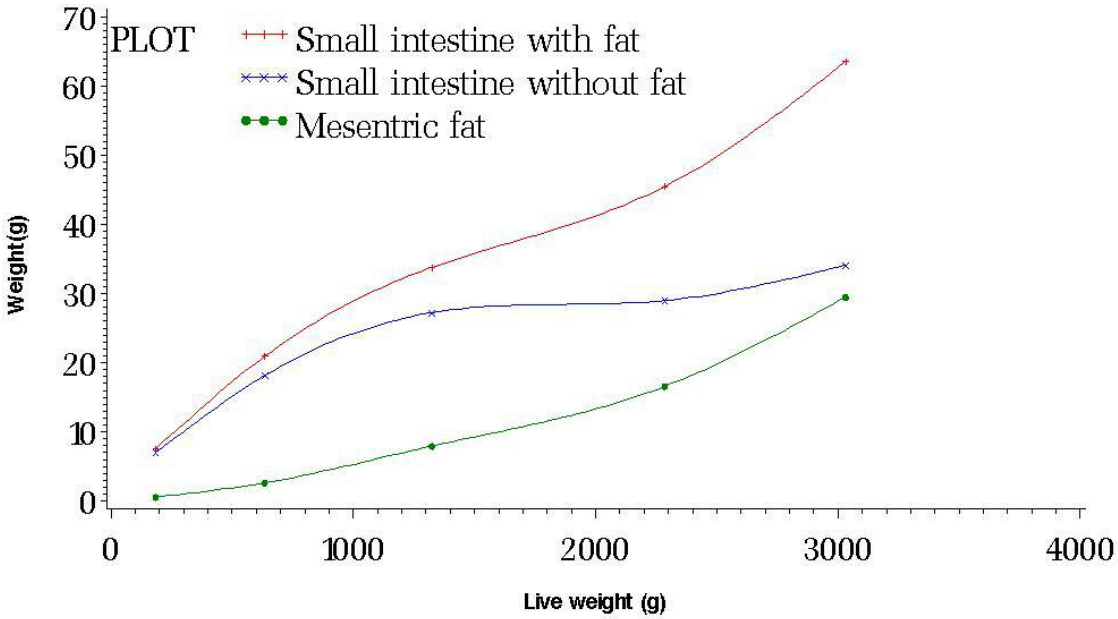

Figure 9. Plot of Small intestine weight with and without fat versus live weight

Abdominal fat = 0.10902 + 0.00495*Live weight + $0.516E^{-5}$*Live weight^2 (R^2=0.85)
Liver = 1.65281 + 0.02207*Live weight - $0.210E^{-5}$*Live weight^2 (R^2=0.94)

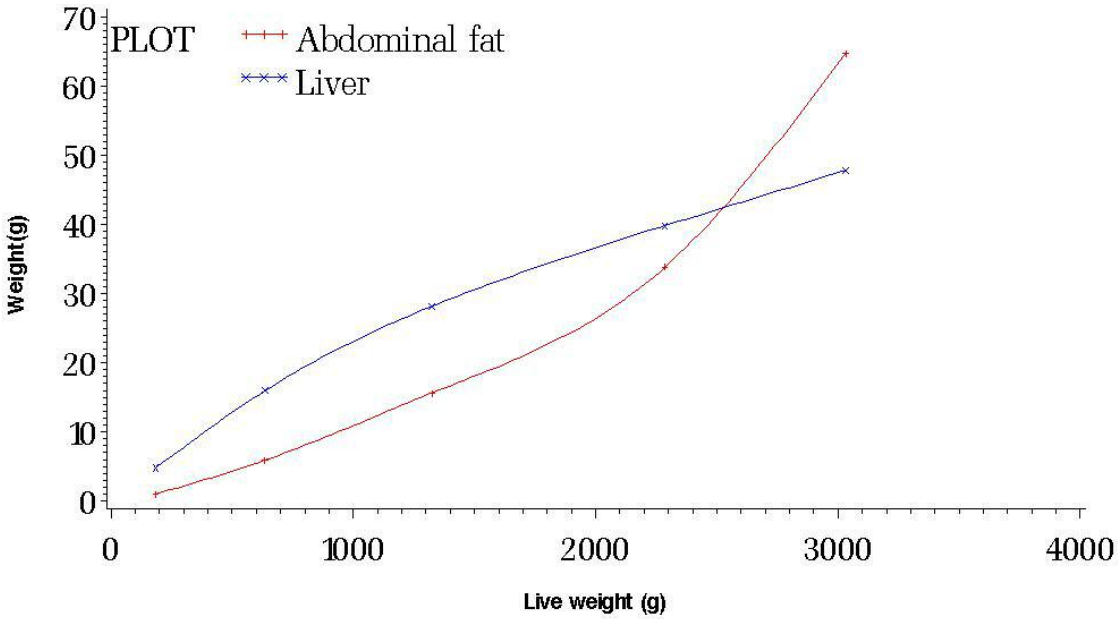

Figure 10. Plot of abdominal fat and liver weight versus live weight

Right Breast with skin = -7.76897 + 0.12126*Carcass weight + $0.754E^{-8}$*Carcass weight^2 (R^2=0.99)
Right Breast without skin = -7.28779 + 0.10481*Carcass weight + $0.0780E^{-8}$*Carcass weight^2 (R^2=0.98)
Skin of Right Breast = -0.28646 + 0.01760*Carcass weight - $0.0379562E^{-8}$*Carcass weight^2 (R^2=0.93)

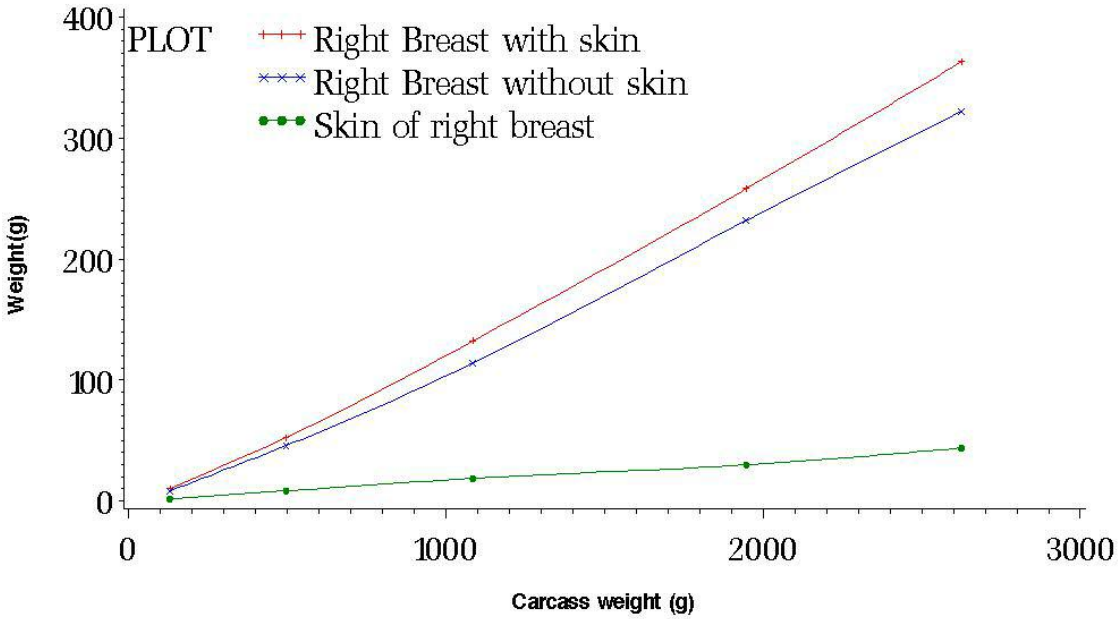

Figure 11. Plot of right breast weight with and without skin versus carcass weight

Left Breast with skin = -8.52944 + 0.12757*Carcass weight + $0.697E^{-5}$*Carcass weight^2 (R^2=0.95)
Left Breast without skin = -6.95087 + 0.10780*Carcass weight + $0.645E^{-5}$*Carcass weight^2 (R^2=0.98)
Skin of Left Breast = -0.01158 + 0.01757*Carcass weight + $0.02034994E^{-5}$*Carcass weight^2 (R^2=0.89)

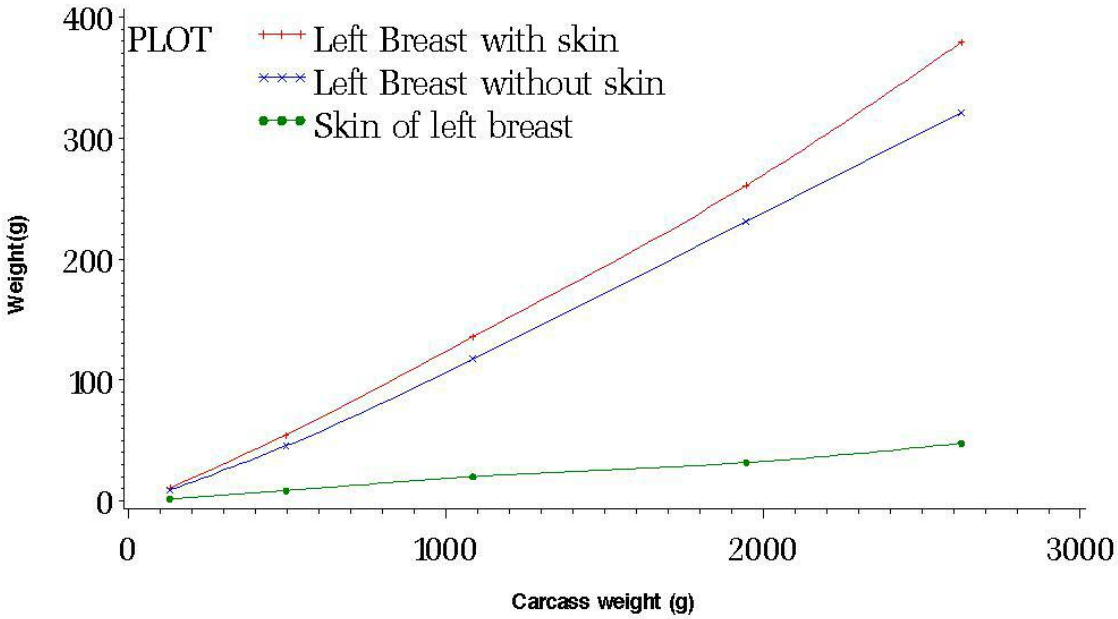

Figure 12. Plot of left breast weight with and without skin versus carcass weight

Right leg with skin = 1.86744 + 0.13798*Carcass weight - 0.024668E^{-5}*Carcass weight^2 (R^2=0.99)
Right leg without skin = 2.32977 + 0.11821*Carcass weight + 0.0901264E^{-5}*Carcass weight^2 (R^2=0.98)
Skin of Right leg = -0.22661 + 0.02166*Carcass weight - 0.162E^{-5}*Carcass weight^2 (R^2=0.94)

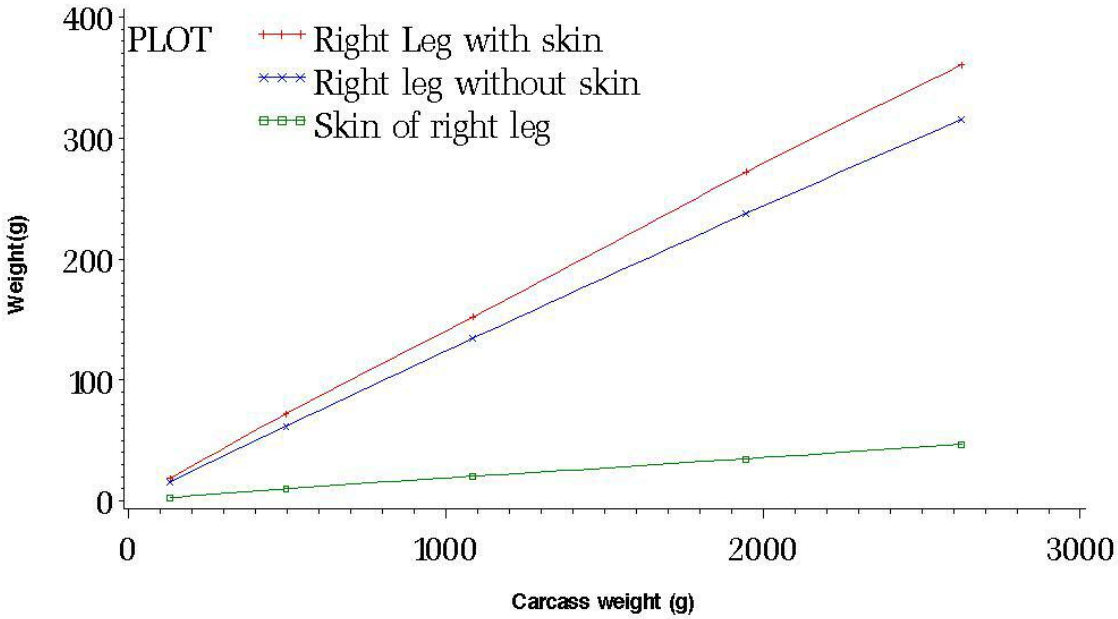

Figure 13. Plot of right leg weight with and without skin versus carcass weight

Left leg with skin = 1.24140 + 0.13857*Carcass weight + $0.128E^{-5}$*Carcass weight^2 (R^2=0.99)
Left leg without skin = 1.34813 + 0.11618*Carcass weight + $0.307E^{-5}$*Carcass weight^2 (R^2=0.99)
Skin of Left leg = 0.17868 + 0.021*Carcass weight - $0.118E^{-5}$*Carcass weight^2 (R^2=0.95)

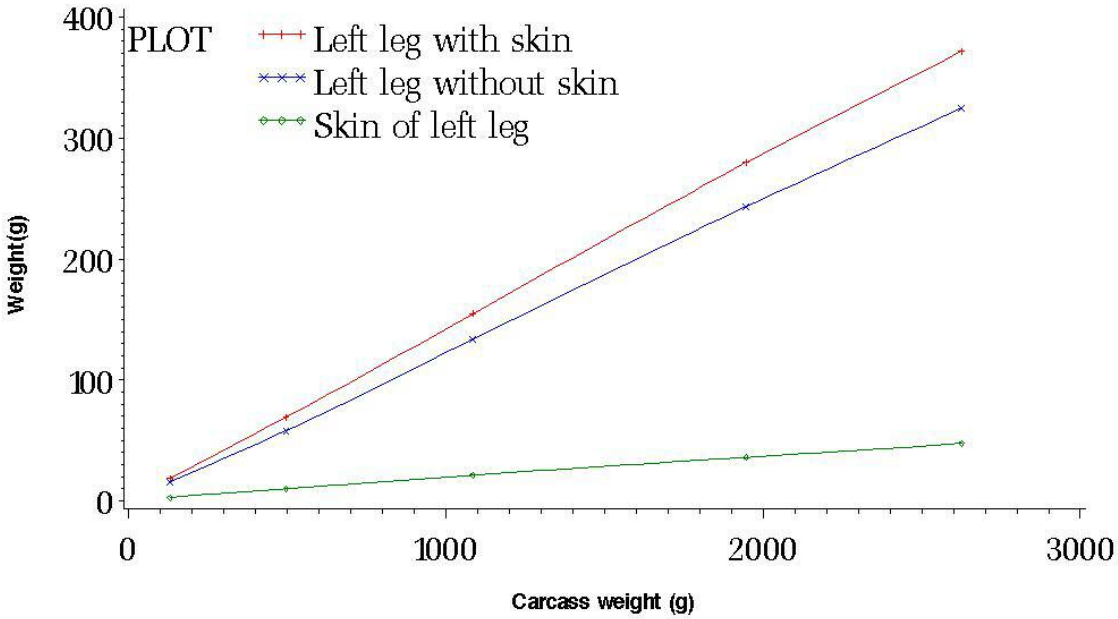

Figure 14. Plot of left leg weight with and without skin versus carcass weight

Right wing with skin = -0.14288 + 0.06067*Carcass weight - 0.575E^{-5}*Carcass weight^2 (R^2=0.98)
Left wing without skin = 0.7816 + 0.06035*Carcass weight - 0.477E^{-5}*Carcass weight^2 (R^2=0.99)

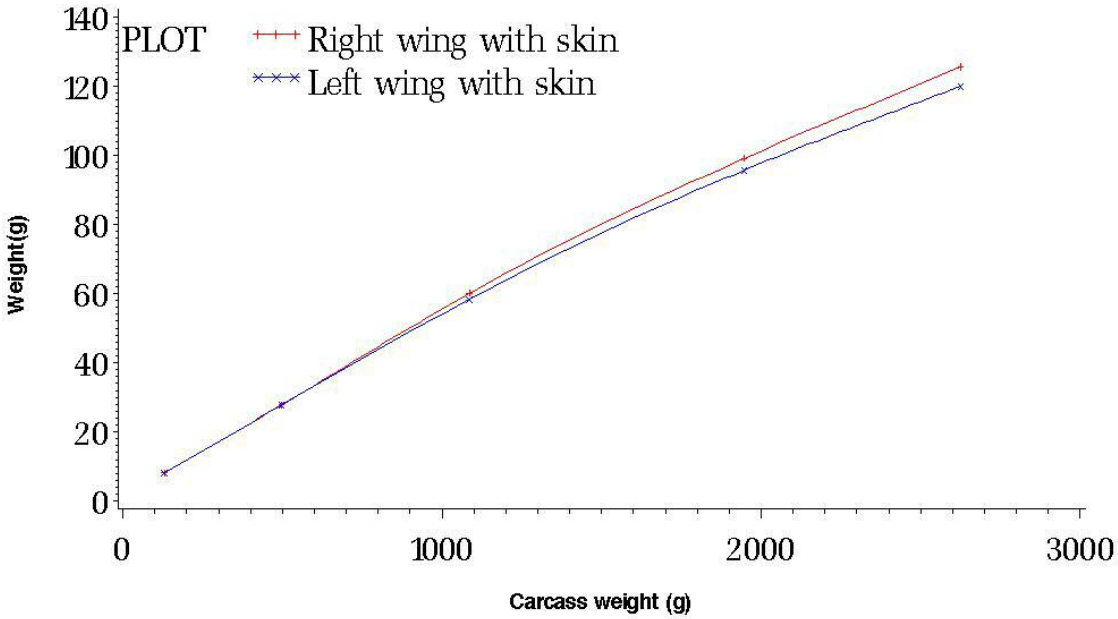

Figure 15. Plot of left and right wing weight with skin versus carcass weight

Gizzard with fat = 4.01973 + 0.02608*Carcass weight - 0.0967896E^{-5}*Carcass weight^2 (R^2=0.88)
Gizzard without fat = 4.81941 + 0.01575*Carcass weight -0.21E^{-5}*Carcass weight^2 (R^2=0.84)
Gizzard fat = -0.29283 + 0.00726*Carcass weight + 0.22E^{-5}*Carcass weight^2 (R^2=0.84)

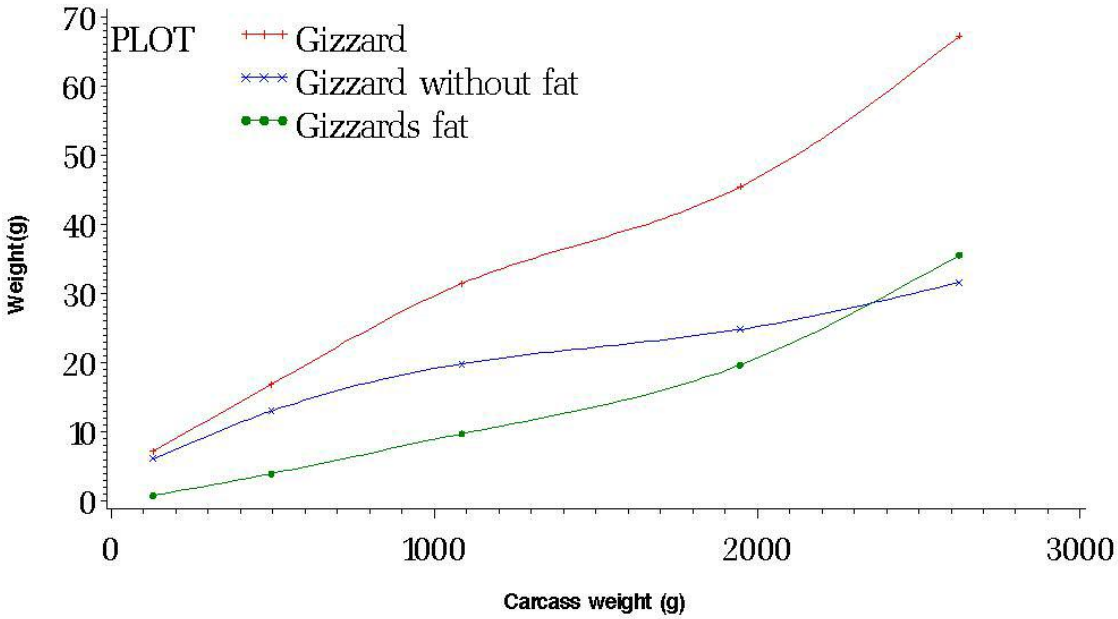

Figure 16. Plot of gizzard weight with and without fat versus carcass weight

Small intestine with fat = 4.58 + 0.03015*Carcass weight - $0.301E^{-5}$*Carcass weight^2 (R^2=0.93)
Small intestine without fat = 4.97215 + 0.02528*Carcass weightE^{-5} - 0.523*Carcass weight^2 (R^2=0.80)
Mesenteric fat = -0.77592 + 0.00678*Carcass weight + $0.159E^{-5}$*Carcass weight^2 (R^2=0.82)

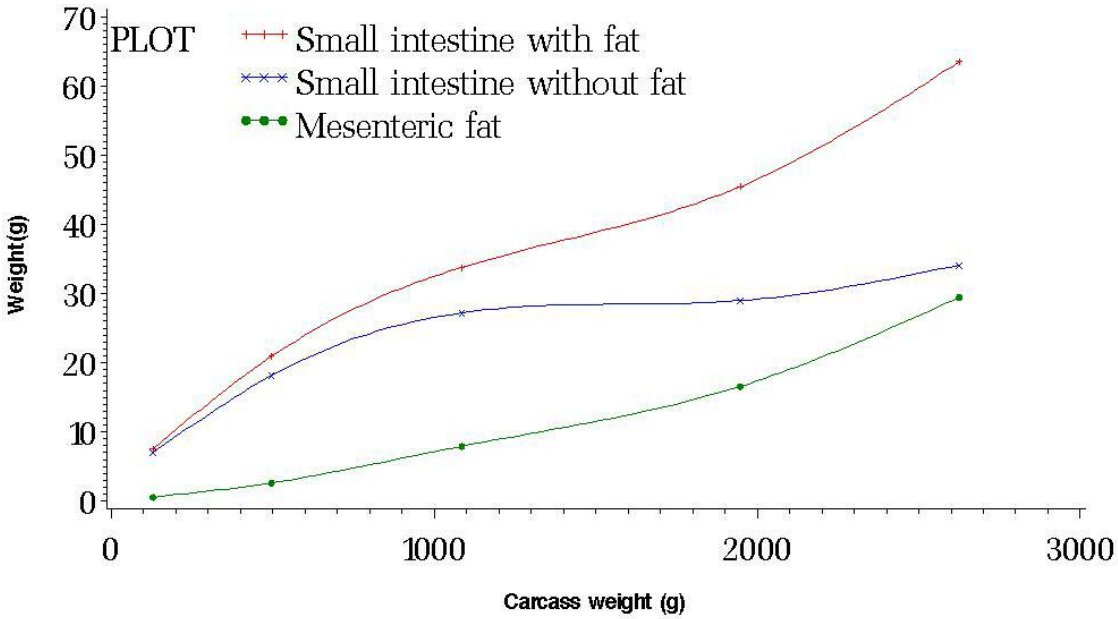

Figure 17. Plot of Small intestine weight with and without fat versus carcass weight

Abdominal fat = -0.26718 + 0.00875*Carcass weight + 0.574E^{-5}-*Carcass weight^2 (R^2=0.85)
Liver = 2.41917 + 0.02631*Carcass weight - 0.8322E^{-5}*Carcass weight^2 (R^2=0.93)

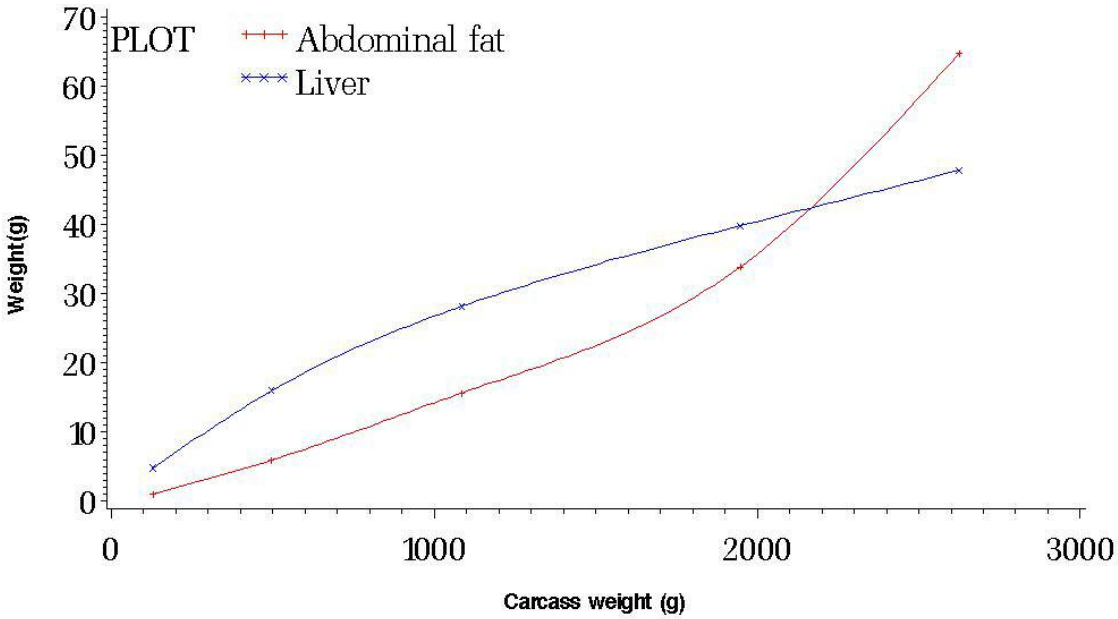

Figure 18. Plot of abdominal fat and liver weight versus carcass weight

Right Breast with skin = 1.05191 + 0.00000763* Carcass weight - 0.145483E^{-6}* Carcass weight^2 (R^2=0.16)
Right Breast without skin = 1.05954 + 0.00000945* Carcass weight - 0.195582E^{-6}* Carcass weight^2 (R^2=0.25)
Skin of Right Breast = 1.00362 -0.00001357* Carcass weight + 0.01771729E^{-6}* Carcass weight^2 (R^2=0.25)

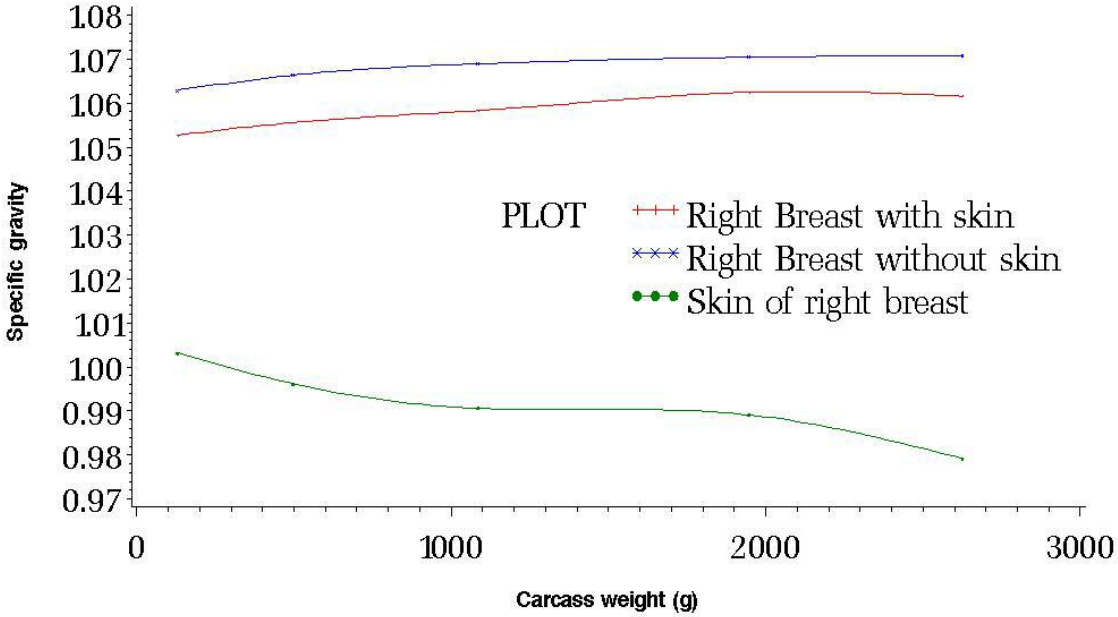

Figure 19. Plot of right breast specific gravity with and without skin versus carcass weight

Left Breast with skin = 1.05266+0.00000699*Carcass weight-0.161663E^{-8}* Carcass weight^2 (R^2=0.08)
Left Breast without skin = 1.05842+ 0.00001269*Carcass weight-0.0323937E^{-8}*Carcass weight^2 (R^2=0.33)
Skin of Left Breast = 1.00631-0.00001989*Carcass weight+0.3552914E^{-8}* Carcass weight^2 (R^2=0.39)

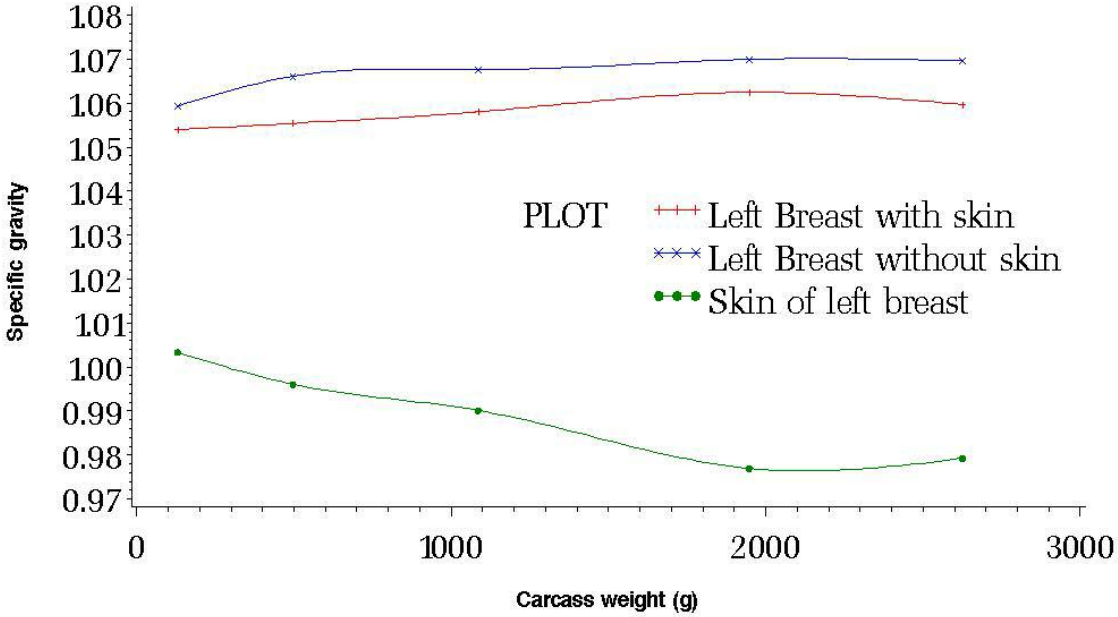

Figure 20. Plot of left breast specific gravity with and without skin versus carcass weight

Right leg with skin = 1.06669 - 0.00000885* Carcass weight + 0.00971486E^{-8}* Carcass weight^2 (R^2=0.43)
Right leg without skin = 1.07127 - 0.00000579* Carcass weight + 0.783122E^{-8}* Carcass weight^2 (R^2=0.28)
Skin of Right leg = 1.01691 - 0.00004737* Carcass weight + 0.09909396E^{-8}* Carcass weight^2 (R^2=0.54)

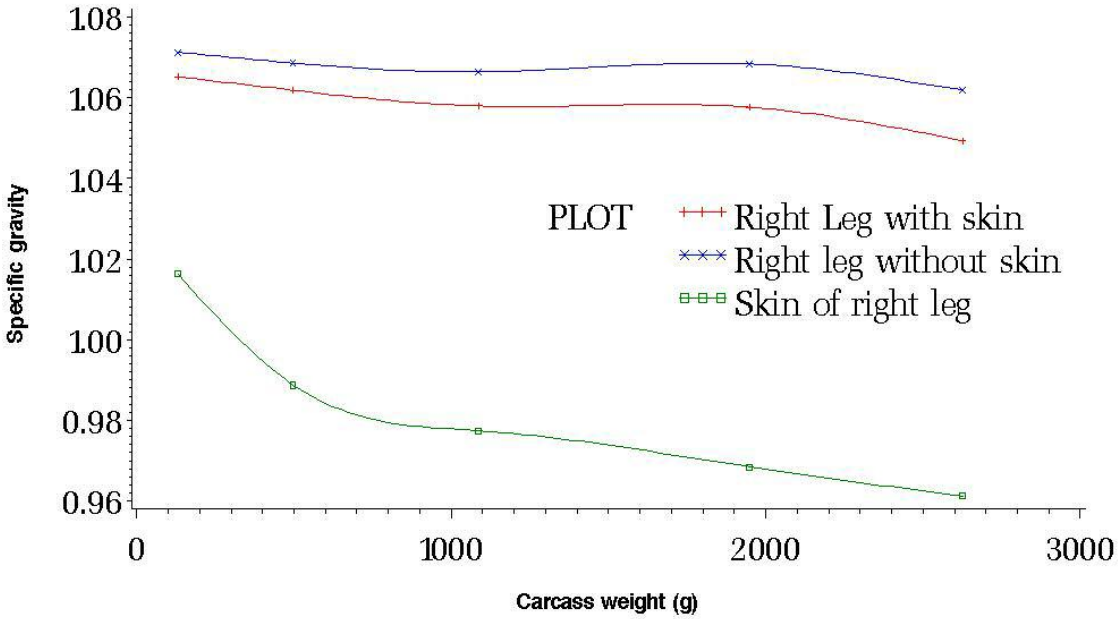

Figure 21. Plot of right leg specific gravity with and without skin versus carcass weight

Left leg with skin = 1.06308 - 0.00000470* Carcass weight - 0.010364E^{-8}* Carcass weight^{2} (R^2=0.35)
Left leg without skin = 1.06999 - 0.00000107* Carcass weight - 0.099906E^{-8}* Carcass weight^{2} (R^2=0.31)
Skin of Left leg = 1.00897 - 0.00003247* Carcass weight - 0.4485993E^{-8}* Carcass weight^{2} (R^2=0.55)

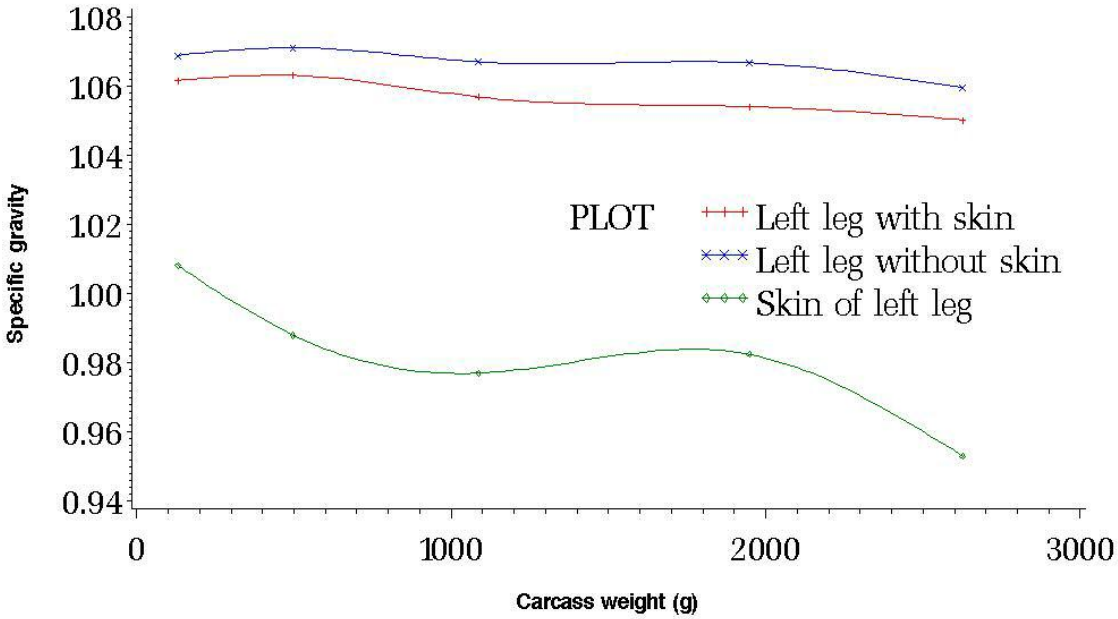

Figure 22. Plot of left leg specific gravity with and without skin versus carcass weight

Right wing with skin = 1.07195 + 0.00000224* Carcass weight - 0.190348E^{-8}* Carcass weight^{2} (R^2=0.10)
Left wing without skin = 1.07694 - 0.00000737* Carcass weight + 0.0948083E^{-8}* Carcass weight^{2} (R^2=0.24)

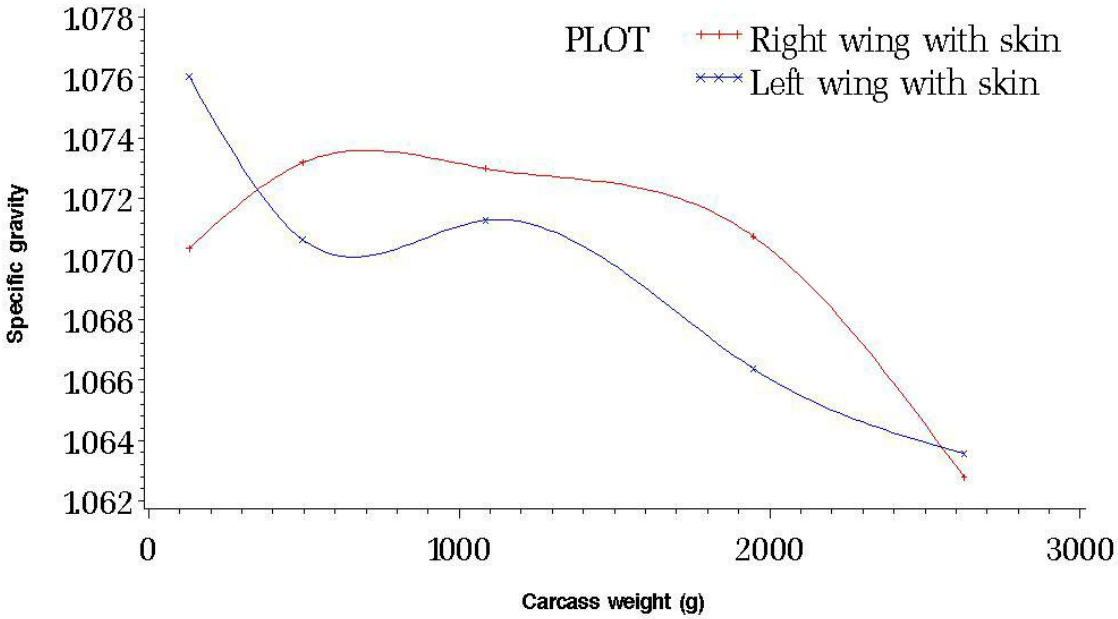

Figure 23. Plot of right and left wing specific gravity with skin versus carcass weight

Gizzard with fat = 1.05673 - 0.00003591* Carcass weight + 0.03611765E^{-7}* Carcass weight ^{2} (R^2=0.82)
Gizzard without fat = 1.05986 + 0.00000578* Carcass weight - 0.0321715E^{-7}* Carcass weight ^{2} (R^2=0.53)
Gizzard fat = 1.02703 - 0.00009928* Carcass weight + 0.2454344E^{-7}* Carcass weight ^{2} (R^2=0.61)

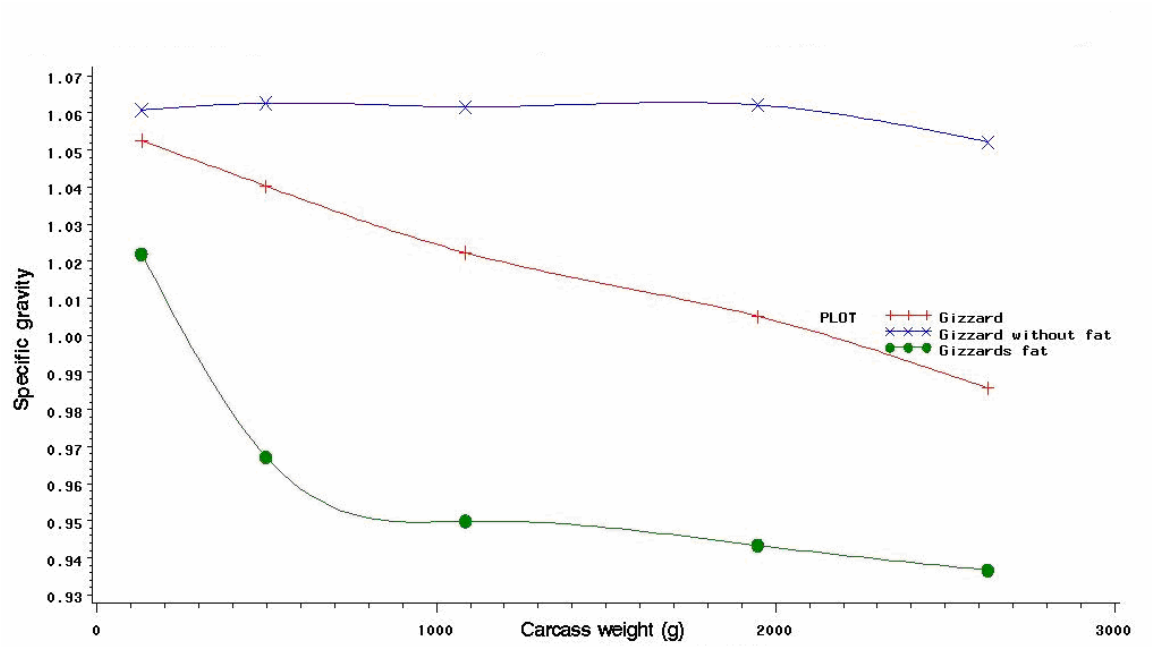

Figure 24. Plot of gizzard specific gravity with and without fat versus carcass weight

Small intestine with fat = 1.0354 - 0.00002228* Carcass weight +0.1761465E^{-8}* Carcass weight ^{2} (R^2=0.73)
Small intestine without fat = 1.03692 -0.00001343* Carcass weight +0.2514971E^{-8}* Carcass weight ^{2} (R^2=0.26)
Mesenteric fat = 1.02339 - 0.00005328* Carcass weight + 0.9571782E^{-8}* Carcass weight ^{2} (R^2=0.47)

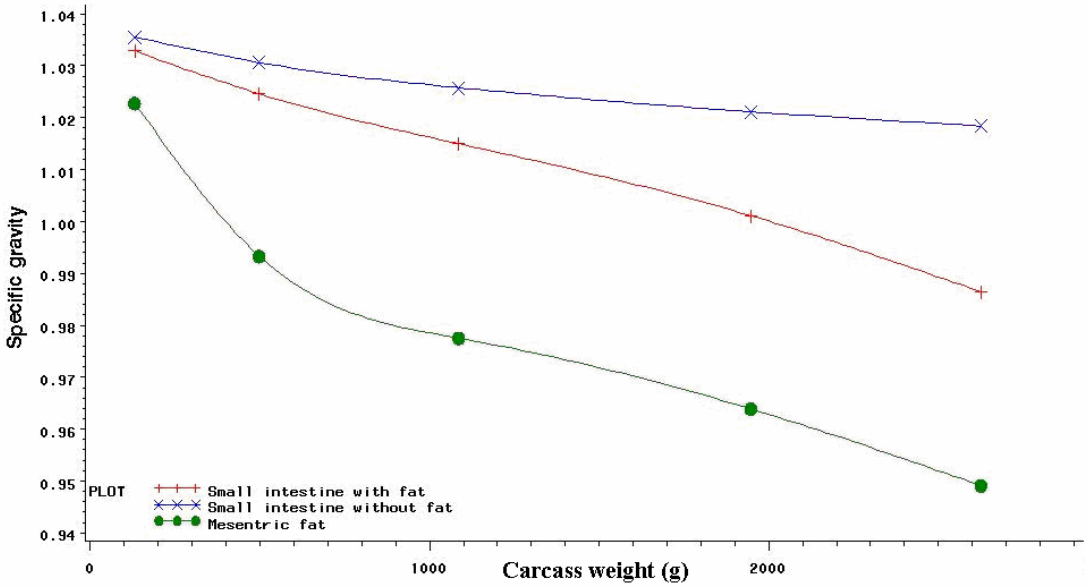

Figure 25. Plot of Small intestine specific gravity with and without fat versus carcass weight

Abdominal fat = 1.00003 -0.000061686* Carcass weight + 0.1369434E^{-7}* Carcass weight ^{2} (R^2=0.71)
Liver = 1.064 + 0.0000057*Carcass weight - 0.0269E-7* Carcass weight^{2} (R^2=0.24)

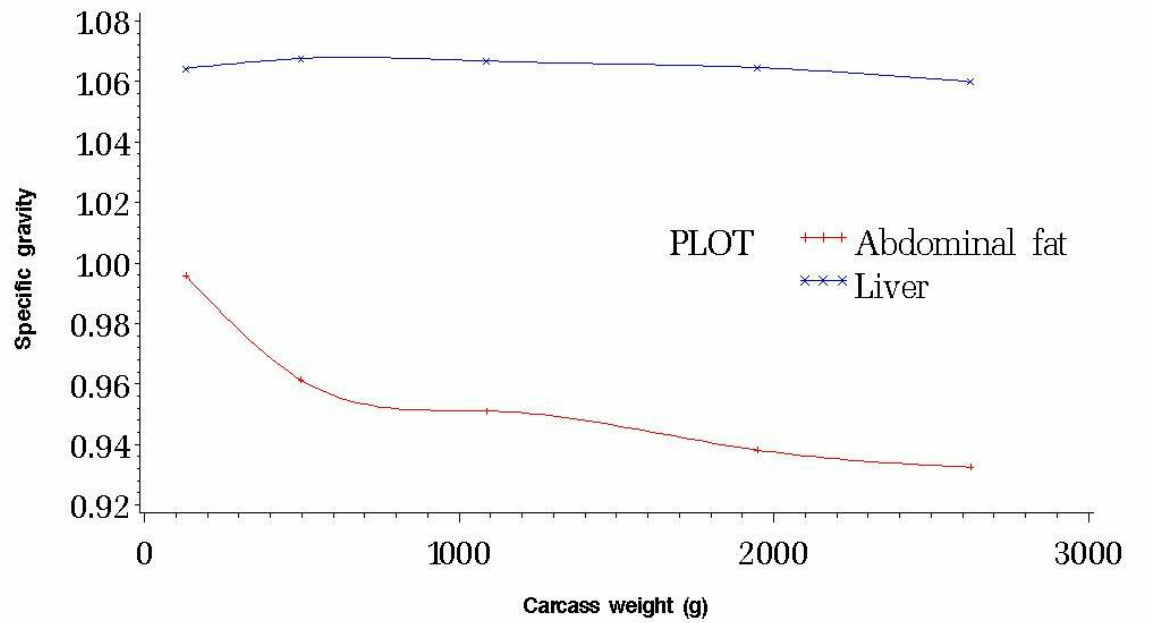

Figure 26. Plot of abdominal fat and liver specific gravity versus carcass weight

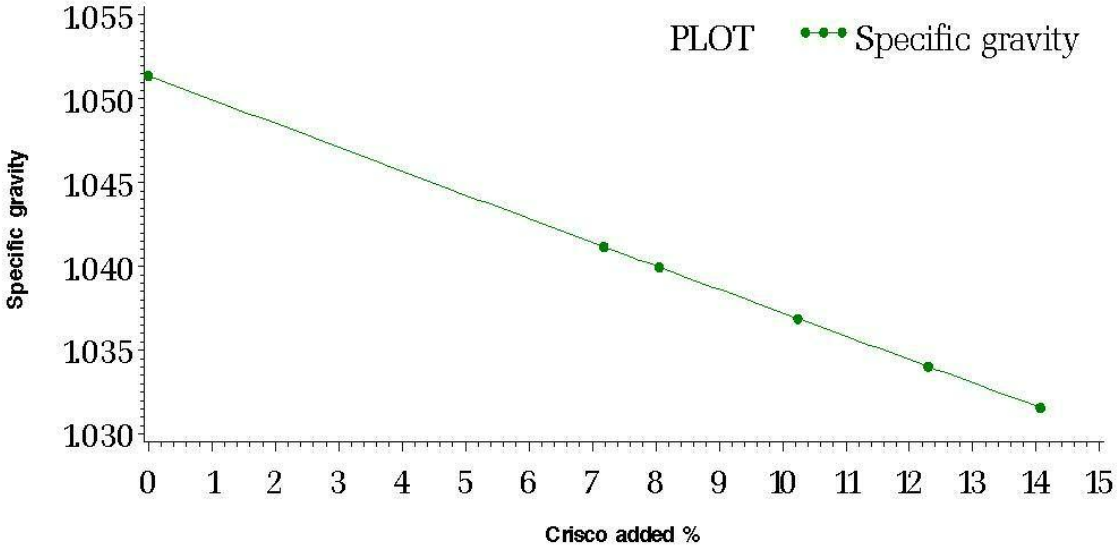

Figure 27. Plot of carcass specific gravity vesus different levels of crisco addition in carcass

Carcass fat = -14.73235 -807.00942* Saturated fat addition (R^2=0.92)

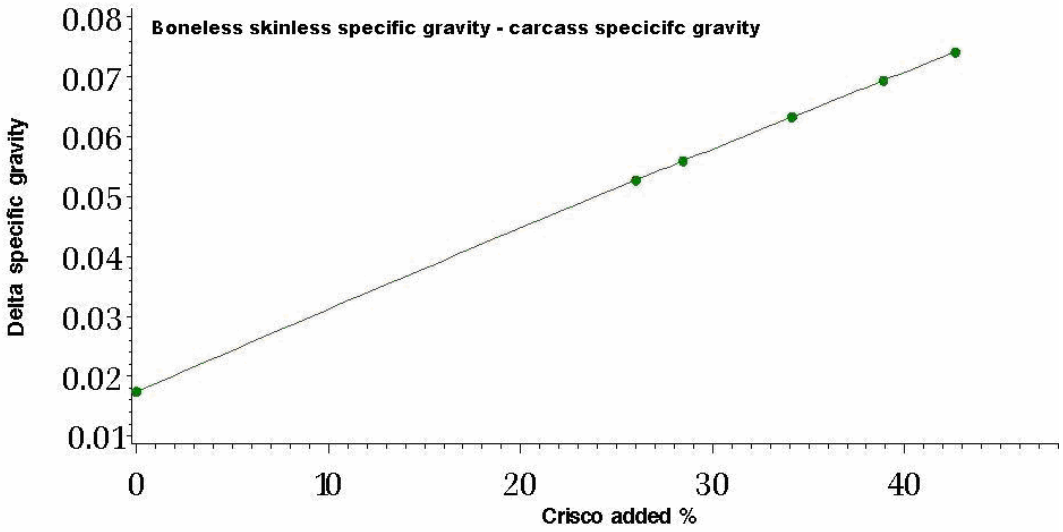

Figure 28. Plot of delta carcass specific gravity versus different levels of saturated fat addition in carcass

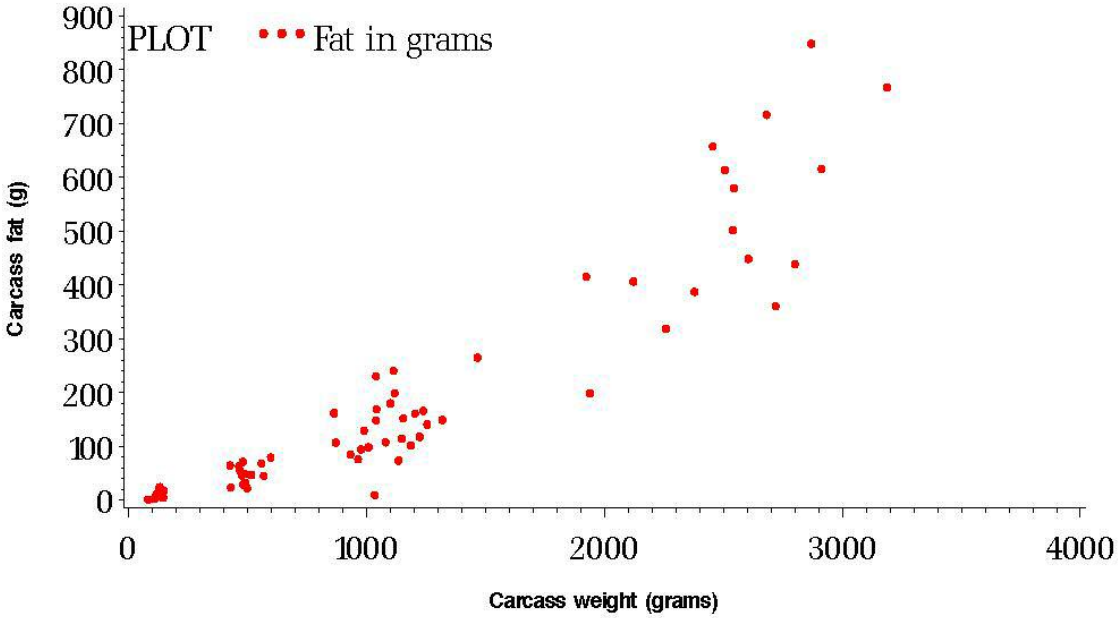

Figure 29. Plot of carcass fat (Scathard procedure)vesus carcass weight

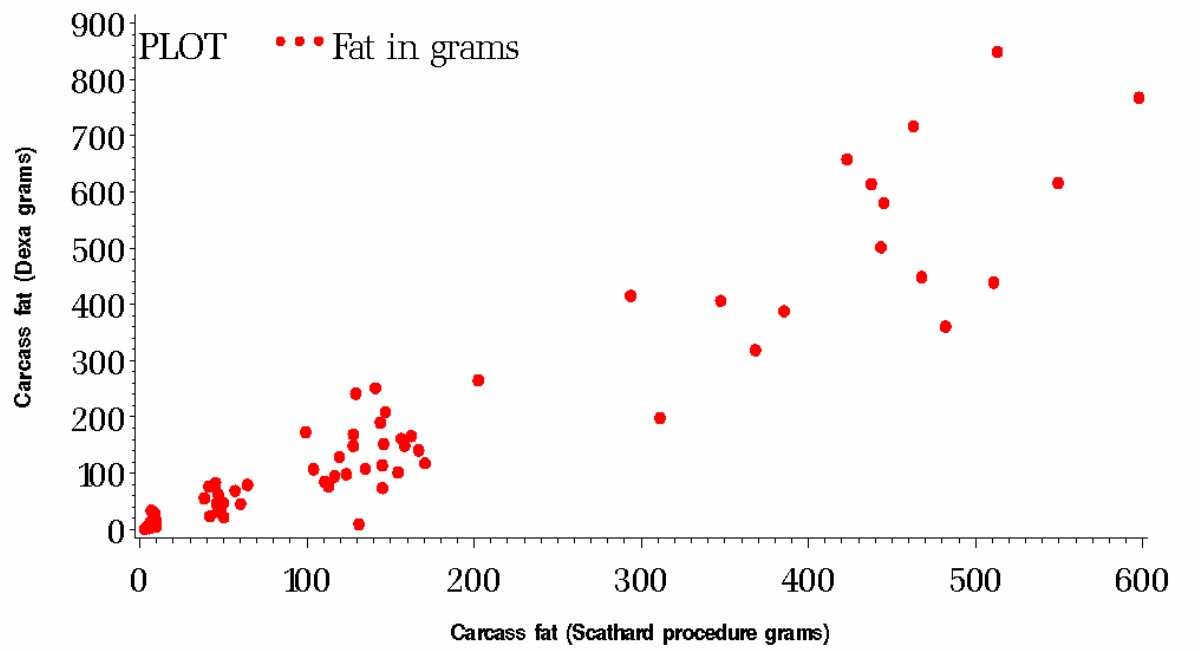

Figure 30. Plot of carcass fat estimated by Scathard procedure vesus carcass fat weight estimated by Dexa

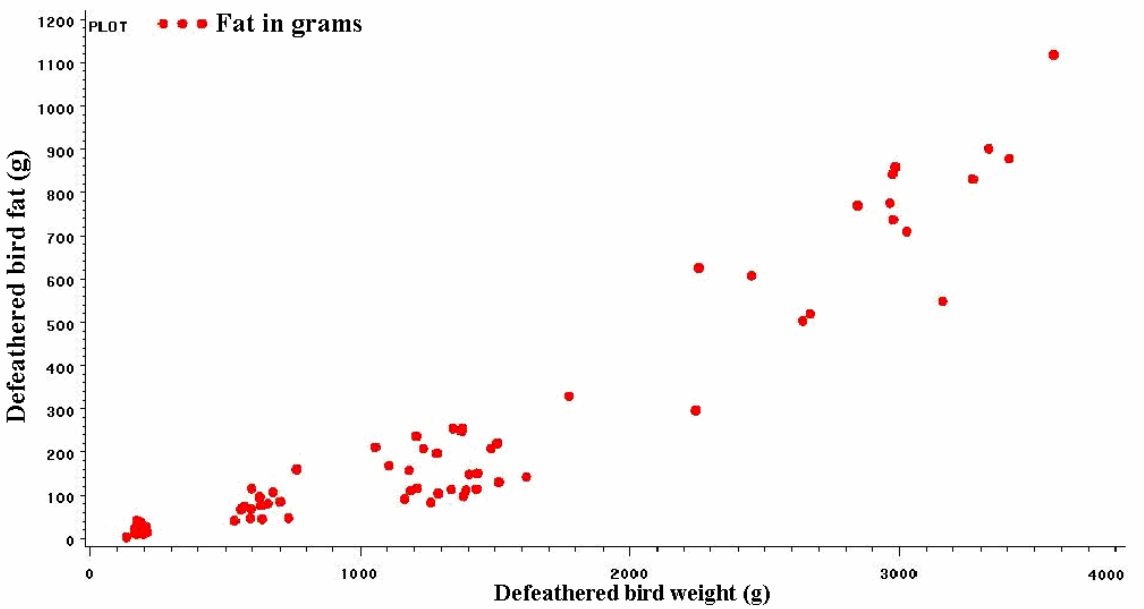

Figure 31. Plot of defeathered bird fat (Standard Addition) versus weight (g)

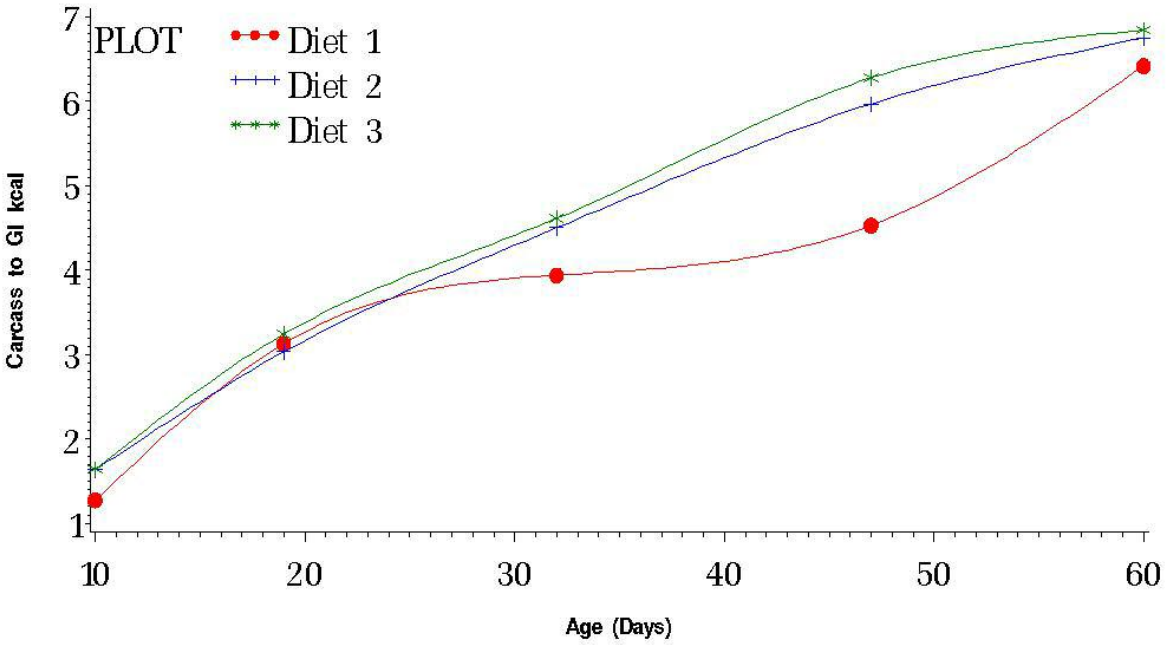

Figure 32. Plot of Carcass to gastrointestinal energy ratio versus age

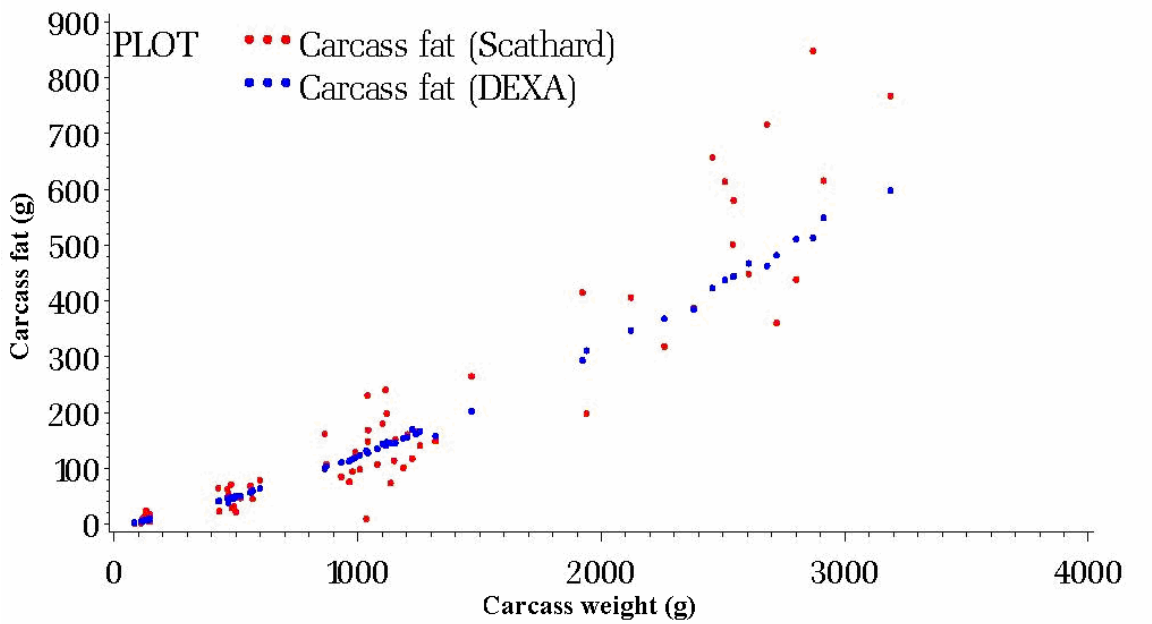

Figure 33. Plot of carcass fat estimated by Scathard and DEXA versus carcass weight

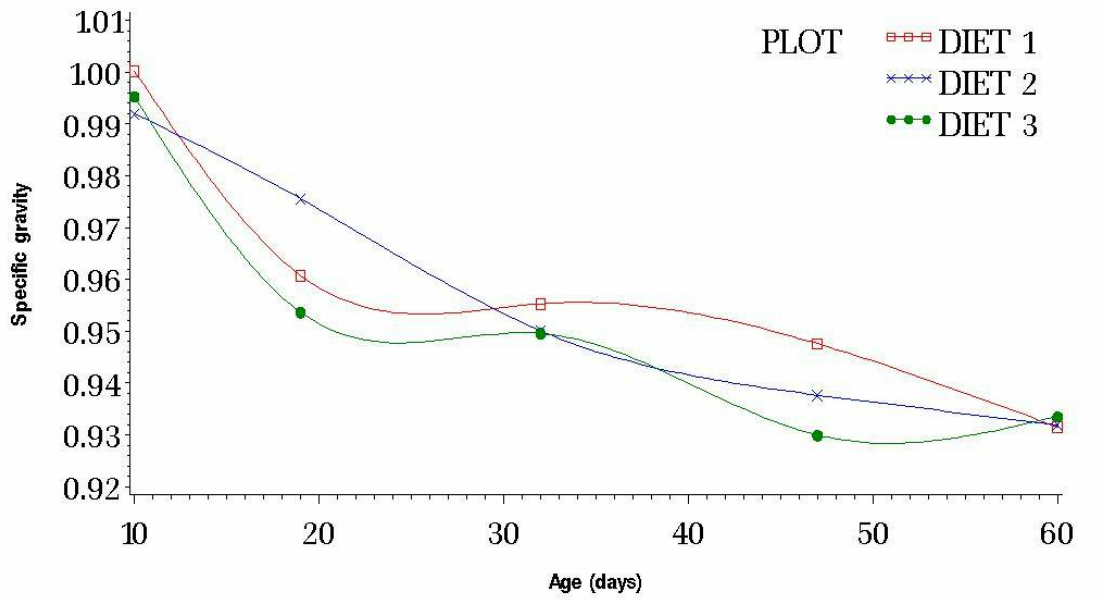

Figure 34. Plot of diet effect on abdominal fat specific gravity versus age

CHAPTER V

FEEDING METHOD EFFECTS UPON PULLET RESPIRATORY QUOTIENT

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ABSTRACT

Breeder pullets are normally fed restricted amount of feed so that their physiological and sexual maturity may be optimally reached. Pullets selected for genetic improvement must be full fed to selection (typically at 6 weeks) and then fed weight reducing diets to lower their weight to be in line with their sexual maturity at about 22 weeks. Two experiments were conducted to describe weight loss and the priority of substrate utilization during feed restriction using both restricted and previously full fed pullets placed on restricted diets. Two hundred day old (Cobb 500) pullets were raised to 84 days in floor pens and then transferred to metabolic chambers for estimation of O_2 consumption and CO_2 production. First study contrasted 5 feeding programs using 40 birds with a previous full fed history. Treatments (T) included T1: Ad libitum; T2: Fed every day at ¼ maintenance; T3: Fed as # T2 with a ketogenic diet; T4: Fed ½ maintenance every other day and T5: Fed as # T4 with a ketogenic diet. The heat production, RQ, weight change and feed consumption were significantly different among the five treatments ($p<0.001$). Treatment 1 birds had the highest value of RQ, heat production/bird/hour and retained more live weight than the other treatment groups ($p<0.05$). Respiratory quotient and heat production of birds fed every day (T2 and T3)

and every other day (T4 and T5) groups were not significantly different ($p>0.05$). Birds consuming ketogenic diet (T3 and T5) exhibited higher heat production than birds consuming the corn soybean diet (T2 and T4). Birds that consumed the ketogenic diet (T3 and T5) lost more weight during the study presumably reflecting ketosis.

The second study contrasted 4 feeding programs in 36 birds with a restricted fed history: T1: Fed to Cobb breeder manual standard; T2.Double the amount of T1 but skip a day; T3. No feed; T4. Double the amount of T1 every day. The RQ and hourly heat production per bird and weight gain were different among the four treatments ($p<0.01$). Treatment 4 birds exhibited a higher value of RQ and heat production compared to the other groups ($p<0.01$). However T3 birds had the lowest RQ and heat production ($p<0.01$). Treatment 1 and 2 bird RQ and heat production were not different ($P>0.05$). All treatments exhibited higher RQ values with the first 6 hour of the feeding period versus last 6 hours before the next feeding. The change in weight was significantly different among four treatments with only T3 birds losing weight. However T1 and T2 bird's weight change was not significantly different. This data indicates that the metabolism of the bird varies with the feed restriction and shifting of RQ from 1 to 0.7 and then back to 0.8 due to shifting of bird metabolism from carbohydrate to fat and then back to protein. Such may be a negative impetus for egg production.

INTRODUCTION

Broiler breeders require feed restriction in the pullet rearing phase in order that they may develop to their full reproductive potential (Macleod et al, 1978; Skyes, 1972). In contrast, genetic advancement necessitates that stock should be raised as broiler

(broilerized) to judge the best birds for the traits of interest, however, once selected the broilerized bird must be transformed back into one that is acceptable for breeder status. This situation creates significant metabolic concerns for the poultry industry.

During the prebreeder feed restriction period, energy is the first limiting nutrient. The daily allotment of feed slows bird growth so that the females weigh just 1.96 kg at 20 weeks of age (Cobb breeder manual, 2003). A concern during the feed restriction period for the pullet prebreeders are that feed consumption forces the bird to catabolize excessive amounts of body proteins and that body lipids are not playing an adequate energy reservoir role (Mbugua et al, 2004). The broilerized pullet to breeder transformation necessitates considerable change in feeding strategy enabling the birds to loose weight. Just how to best assist this bird in the needed weight reduction is unknown, but to let them retain the high body mass markedly lowers subsequent egg production (Bartov et al, 1998).

Feed restriction methods may be as small amounts of feed fed every day. Alternatively, a feed restriction method used in the US is every-other-day (EOD; or 'skip-a-day') feeding. With that system, broiler breeders are provided twice their daily allowance of feed every other day (Pym, 1969). This system has been reported to result in greater flock uniformity than every day feeding (Bartov et al, 1998). Such a system may enable greater lipid accretion and its use as an energy reservoir (Snesinger and Zimmerman1974). Macleod and Shannon (1978) reported that in pullets feed restriction up to 80% of ME reduces the metabolic rate per unit of metabolic weight. The 6 week broilerized bird has similar body protein to the 20 week pullet but considerably more lipid. The purpose of this study is to gain insight into the markedly different needs of the

pullet reared to become a breeder and the broilerized pullet reared initially as a broiler and then transformed into a breeder.

MATERIAL AND METHODS

Two hundred day old (Cobb 500) pullets were received from a commercial hatchery. Upon the arrival of birds at the OSU poultry farm, birds were weighed, wing banded and placed randomly into four floor pens with fresh wood shavings. Birds were divided into two groups; Adlib (A) and Restricted fed according to Cobb breeder manual® (Table 1). Brooders were set to provide adequate temperature. Chicks were given a starter diet containing 22.1% CP and 3,053 Kcal/kg ME. At the age of 21 days birds were shifted to grower feed having 19.8% CP and 3,131 Kcal/kg ME (Table 4). Two experiments were conducted for two different ages of pullets.

EXPERIMENT 1

At 6 weeks of age, 42 birds having ad libitum feeding history were moved to metabolic chambers. There were a total of 5 treatments, (T1): Previously full fed birds with continued ad libitum access to feed; (T2): Previously full fed birds fed every day at ¼ maintenance level as [110 x body size $**^{0.75}$]; (T3): Previously full fed birds fed every day at ¼ maintenance level as [110 x body size $**^{0.75}$] ketogenic diet; (T4): Previously full fed birds fed ½ maintenance level as [110 x body size $**^{0.75}$] every other day; (T5): Previously full fed birds fed ½ maintenance level as [110 x body size $**^{0.75}$] every other day ketogenic diet. These five treatments were randomly assigned to metabolic chambers (Table 4). In the metabolic chambers all the treatments except T4 and T5 were fed with corn soybean diet (Table 2). For T4 and T5 a special ketogenic diet was made from

soybean meal (Table 3). A ketogenic diet might offer the possibility to shift this weight loss towards lipid and preserve body proteins.

EXPERIMENT 2.

At the age of 12 weeks, thirty six birds were randomly selected. Birds were initially weighed and divided into three categories Small (< 1300g), Medium (>1300g) and Large (>1500g) according to their weights and put in metabolic chambers. The birds were randomly assigned to four different treatments according to the feeding level (T1). Fed like Cobb manual; (T2).Double the amount of T1 but skip a day; (T3). No feed; T4. Double the amount of T1 every day. In each metabolic chamber, there was 1bird/rep and 9 reps per treatment (Table 2). In the metabolic chamber, all birds were fed corn soybean diet (Table 2).

METABOLIC CHAMBERS

The general characteristics and methodology used in metabolic studies have been described previously (Belay and Teeter, 1993**;** Weirnusz and Teeter, 1993). Birds were kept for 180 hours and 70 hours in the metabolic chamber during experiment one and two, respectively. Birds had full access to water. The lighting schedule was 23L: 1D. The idea behind one hour's dark period is to get BMR in the absence of activity. At the end of the trial birds were weighed. While birds were in metabolic chambers, oxygen consumption and carbon dioxide production was monitored. RQ was estimated as the ratio of CO_2 production to O_2 consumption. Heat production was estimated using Brouwer equation (Hp (kJ) = 16.18 O_2 + 5.02 CO_2) (Brouwer, 1958).

FEEDING AND WATER

The corn soybean meal based ration composition is displayed in Table 2. Birds were reared on a typical basal diet containing 22.1% CP and 3,050 Kcal/kg ME during the starter phase (hatch through 21d) provided as a mash. On day 21 birds were switched to the pelleted grower feed. The pelleted grower ration contained 19.8% CP and 3,131 Kcal/kg ME through 12 weeks. The birds were fed according to the Cobb breeder manual (2003) to 12 weeks of age (Table 1). Since the metabolic energy of the diet was higher than the recommended amount (Cobb breeder manual, 2003), it was fed at 90% of the recommended amount. In the metabolic chambers birds were fed according to their treatment at 10.00 AM. Feeding was accomplished by weighing feed and placing it in the feeder from the small opening present on the top of chamber. By this manner the metabolic chambers remained sealed. Birds had ad libitum access to water throughout the study.

MANAGEMENT

Birds were reared according to the Cobb Vantress and OSU husbandry guide to 12 weeks of age in floor pens. The metabolic chambers lighting program consisted of 23L: 1D. At the end of the study birds were removed from the metabolic chambers and their weight and feed weigh back recorded.

VARIABLES MONITERED

In the metabolic chambers, bird feed consumption, bird weight change, O_2 consumption, and CO_2 production were measured. RQ was calculated as the ratio of CO_2 production to O_2 consumption and heat production was estimated using Brouwer equation (Hp (kJ) = 16.18 O_2 + 5.02 CO_2) (Brouwer, 1958). This measurement of heat

production will provide a continuous measurement of energy expenditure and of substrate type being categorized as RQ. Body temperature (BT) was measured periodically during the 7 days chamber period to determine if feeding program affects baseline body temperature.

STATISTICAL ANALYSIS

The data were analyzed for each experiment and also for each feeding cycle over the experiment duration. Statistical analysis software (SAS) was used for estimation of treatment effects on the RQ, heat production and weight change. Least square means were used to separate the treatment means. Difference among treatments was identified with Least significant differences at $P< 0.05$ or as otherwise reported.

RESULTS AND DISCUSSION

EXPERIMENTS 1

The heat production, RQ, weight change and feed consumption are displayed in Table 6. All these variables were significantly different among five treatments ($p<0.001$). T1 birds had the highest value of RQ and were significantly different from other groups ($p < 0.05$). Since T1 birds had ad libitum feeding, they were metabolizing carbohydrate with a RQ close to one. However, RQ of T2 and T3 birds were significantly different from each other ($p<0.05$). Since the T3 group was consuming the ketogenic diet, RQ was close to 0.8 indicating that they were metabolizing protein. However, the T4 and T5 groups were not different ($p>0.1$) from each other. The birds of T3 and T5 group exhibited the lowest RQ value as expected and it can be explained due to the ketogenic effect of soybean meal. As we expected, the T2 and T4 groups were not significantly

different since they were getting the same amount of feed. Similarly RQ value of T3 and T5 was not significantly different from each other.

The heat production per bird per hour was significantly different among five treatments ($p< 0.01$). T1 birds exhibited highest value of heat production and was different from other group (T2, T3, T4 and T5, $p<0.01$). Even though the T2 and T3 groups were receiving the same amount of feed their heat production was significantly different from each other ($p<0.05$) indicating that T3 birds were metabolizing protein. Similarly the heat production of T4 and T5 groups were significantly different from each other ($p < 0.05$, Table 6).

The change in weight during the study was significantly different among treatments ($p<0.01$) and displayed in Table 6. However, weight change was not significantly different among T2, T3 and T5, however T1 and T4 were significantly different from other groups. T1 group exhibited less weight loss with their ad libitum feeding, reflecting their increased feed consumption.

Feed consumption during the study is displayed in table 6 and is significantly different among treatments. The T1 birds consumed maximum feed since they were fed ad libitum. However, birds receiving ketogenic diet (T3 and T5) consumed significantly less feed than groups that were fed on corn soybean ration (T2 and T4) and lose more weight.

EXPERIMENT 2

The RQ, hourly heat production per bird and weight gain are displayed in Table 7. The respiratory coefficient was significantly different among the four treatments ($p<0.01$). T4 birds exhibited the highest value of RQ while T3 birds had the lowest. Since

T4 birds had ad libitum feeding, they were metabolizing carbohydrate with an RQ close to one. In contrast, the T3 birds were fasted with an RQ close to 0.8, suggesting that they were metabolizing protein. The T1 and T2 birds receiving the same amount of feed and had similar RQ. The feeding periods were divided into feed period one (after feeding) and feed period two (before feeding). All the treatments had a higher RQ value during feed period one than feed period two. During the feed period one, birds were just fed and they were catabolizing carbohydrate and their RQ was close to one. In feed period two bird metabolism shifted more towards lipid and their RQ was close to 0.9. However T3 birds had constant RQ throughout the experiment and it's was close to 0.8, as they were metabolizing protein for energy production.

The heat production Kcal/hr/bird was significantly different among all the treatments. As expected, T4 birds exhibited the highest heat production while T3 birds had the least. However T1 and T2 groups heat production Kcal/hr/bird was not significantly different because they were getting the same amount of feed. During feed period one the heat production Kcal/hr/bird was higher than feed period two. The change in weight was significantly different among four treatments. Except for T3 birds, all other treatments gained weight. Since both T1 and T2 birds were getting the same amount of feed, there was no significant difference in weight change between T1 and T2. However, T3 birds lost weight since they were getting no feed. T4 birds gained highest weight because they were getting ad libitum feed.

CONCLUSION

Data indicated that feed restriction have significant effects on substrate metabolism. In experiment 1, both RQ and heat production (kcal/bird/hour) for T1 group was higher than other group. However, the every day and every other day feeding group (T2 and T4) had RQ around 0.8 and may suggest that birds were metabolizing protein for energy production. In experiment 2, the restricted fed birds showed variation in the RQ and heat production. The best diet to assist broilerized birds returning to a pullet with breeding potential is the ketogenic diet. Similarly between every day and every other day feeding suggests that they may be interchanged.

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TABLE 1. Feeding schedule for pullets throughout week 12

Age (Weeks)	Feed/Day/Bird (g)*	Actual Feed/Day/Bird (90%) (g)#
1	Adlib	Adlib
2	35	31.5
3	36	32.4
4	42	37.8
5	45	40.5
6	48	43.2
7	51	45.9
8	52	46.8
9	54	48.6
10	56	50.4
11	57	51.3
12	58	52.2

*According to Cobb breeder manual 2003; # Actual amount fed to pullets

TABLE 2. Composition of corn soybean diet

	Age interval (days)	
	0 to 21	21 to 72
Ingredient, %	Virginiamycin	Virginiamycin
Corn	58.3	64.529
Soybean meal (48 % CP)	34.56	28.21
Soybean oil	2.83	2.93
Dicalcium phosphate	1.87	1.98
Limestone	1.18	0.92
NaCl	0.35	0.29
Roche Vitamin Premix[2]	0.2	0.2
$NaHCO_3$	0.24	0.32
DL-Methionine	0.21	0.22
Huber trace mineral[3]	0.09	0.09
Lysine HCl	0.06	0.157
Selenium 600 premix	0.04	0.04
Threonine	0.02	0.05
Ethoxyquin	0.01	0.012
Choline Chloride	0.01	0
Copper Sulfate	0	0.002
L-Arginine	0.03	0.05
Sacox-60® (Salinomycin)	0.05	0.05
Stafac-20® (Virginiamycin)	0.05	0.05
Calculated Analysis		
Me_n (kcal/kg)	3053	3,131
CP, %	22.1	19.8
Arg	1.38	1.30
Lys	1.12	1.14
Met	0.51	0.52
TSAA	0.83	0.88
Ca	0.90	0.80
P, available	0.44	0.40

[1]Supplied per kilogram of diet: vitamin A, 10,141 IU (retinyl acetate); cholecalciferol, 3,086 IU; vitamin E, 23.92 IU (dl-α-tocopheryl acetate); menadione, 2.87 mg; thiamine, 2.20 mg; riboflavin, 7.72 mg; niacin, 60.30 mg; d-pantothenic acid, 12.46 mg; pyridoxine, 3.75 mg; vitamin B_{12}, 0.017 mg; folic acid, 1.066 mg; d-biotin, 0.127 mg. [3]Supplied per kilogram of diet: Ca,160 mg; Zn, 100 mg; Mn, 120 mg; Fe,75 mg; Cu, 10 mg; I, 2.5 mg.

TABLE 3. Composition of ketogenic diet for experiment two

Ingredients	% age
Soybean meal	93.81%
vitamin premix[1]	0.35%
trace mineral[2]	0.05%
Calcium carbonate	4.56%
Selenium	0.02%
Salt	0.20%
NaHCO3	1.0%
Ethoxyquin	0 .01%

[1]Supplied per kilogram of diet: vitamin A, 10,141 IU (retinyl acetate); cholecalciferol, 3,086 IU; vitamin E, 23.92 IU (dl-α-tocopheryl acetate); menadione, 2.87 mg; thiamine, 2.20 mg; riboflavin, 7.72 mg; niacin, 60.30 mg; d-pantothenic acid, 12.46 mg; pyridoxine, 3.75 mg; vitamin B_{12}, 0.017 mg; folic acid, 1.066 mg; d-biotin, 0.127 mg. [2]Supplied per kilogram of diet: Ca,160 mg; Zn, 100 mg; Mn, 120 mg; Fe,75 mg; Cu, 10 mg; I, 2.5 mg

TABLE 4. **Treatments, replicates (reps) and number of birds used in experiment one**

Treatment #	Treatment type		Reps	Birds/rep
	Bird type	Feeding type		
T1	F	AL	6	1
T2	F	ED ¼ MEm	9	1
T3	F	ED ¼ MEm KD	9	1
T4	F	EOD ½ MEm	9	1
T5	F	EOD ½ MEm KD	9	1

ED: Every day; EOD: Every other day; AL: adlibitum; MEm: 110 x body size $**^{0.75}$;
KD: Ketogenic diet; R: Restricted fed (Cobb manual); F: Birds with Full fed history

TABLE 5. Treatments, replicates (reps) and number of birds used in experiment two

Treatment	Treatment Type	Reps	Birds/Rep	Total
T1	Feeding According to Cobb manual (52.2 g)	9	1	9
T2	Double the amount of T1 but skip a day	9	1	9
T3	No feed	9	1	9
T4	Double the amount of T1 every day (104.4g)	9	1	9

TABLE 6: Heat production and respiratory quotient for experiment one

Treatments	Feed type	Heat production Kcal/hr/bird	RQ	Weight loss (g)	Feed consumed (g)
Ad libitum (T1)	Corn soybean	6.71^{a}	1.02^{a}	28.9^{a}	808.2^{a}
Every day ¼ ME (T2)	Corn soybean	3.68^{b}	0.94^{b}	149.9^{b}	133.6^{b}
Every day ¼ ME (T3)	Ketogenic diet	4.82^{c}	0.86^{c}	190.5^{b}	76.8^{c}
Every other day ½ ME (T4)	Corn soybean	3.93^{b}	0.92^{bc}	37.8^{a}	139.7^{b}
Every other day ½ ME (T5)	Ketogenic diet	4.83^{c}	0.89^{bc}	182.6^{b}	67.9^{c}
P Value		<0.0001	<0.0002	<0.0001	<0.0001

ME: 110 x body size $**^{0.75}$; Heat production kcal/bird/hour: (Hp (kJ) = 16.18 O_2 + 5.02 CO_2) (Brouwer, 1958);
RQ: CO_2 production/O_2 consumed; Weight change = Initial weight – Final weight; Feed consumed: (Feed offered – Feed weigh back);
Values obtained by SAS from ANOVA table; ^{bc} shows the difference in mean

TABLE 7. Respiratory quotient, heat production, weight change and feed consumption of different feeding periods for experiment two

Treatment	Feed (g)	Respiratory quotient			Heat production Kcal/hr/bird			Weight gain (g)
		Overall	Interval		Overall	Interval		
			FP 1	FP 2		FP 1	FP 2	
Every day (T1)	52.2	0.92^{a}	0.96^{a}	0.88^{b}	4.4^{a}	4.8^{a}	4.0^{b}	40.4^{a}
Every other day (T2)	104.4	0.92^{a}	0.95^{a}	0.88^{b}	4.4^{a}	4.7^{a}	4.1^{b}	20.7^{a}
No feed (T3)	0	0.79^{b}	0.82^{a}	0.77^{b}	2.8^{b}	3.1^{a}	2.6^{a}	-224.6^{b}
Every day (T4)	104.4	0.98^{c}	0.98^{a}	0.98^{a}	5.3^{c}	5.6^{a}	5.0^{b}	318.9^{c}
P value		<0. 01	<0. 01	<0. 01	<0. 01	<0. 01	<0. 01	<0. 01

Weight change = Initial weight – Final weight; FP 1: Feed period one (6 hours after feeding);
FP 2: Feed period two (6 hours before feeding); (Hp (kJ) = 16.18 O_2 + 5.02 CO_2) (Brouwer, 1958); RQ: CO_2 production/O_2 consumed;
Values obtained by SAS from ANOVA table

VITA

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Name: Manpreet Singh Date of Degree: July, 2007

Institution: Oklahoma State University Location: Stillwater, Oklahoma

Title of Study: FACTORS INFLUENCING ENERGY METABOLISM IN BROILERS AND PULLETS

Pages in Study: 124 Candidate for the Degree of Master of Science

Major Field: Animal Science

Scope and Method of Study: Three experiments were conducted to examine the influenced of three factors on energy metabolism in broilers and pullets. The first experiment was conducted to judge the effect of electrolyzed water as an alternative to growth promoting antibiotics on growth and performance of broilers. The study contrasted electrolyzed water at 25ppm with virginiamycin™ at 20ppm for efficacy versus a nonmedicated control. The second experiment was conducted to determine the effects of nutrition and management on the fat deposition pattern of broiler across the growth curve and to propose a bird composition that optimizes calorie conversion to live weight for the industry and health concerns of the consumer. The study contrasted a mash diet with mash plus soybean oil (187 kcals MEn / kg diet) and steam pelleted mash. The third experiment was conducted to contrast pullet feeding methods as every day versus every other day as well as feed type (corn soybean vs ketogenic diet) on the energy balance and RQ of broilerized and restricted fed pullets.

Findings and Conclusions: Experiment one: Electrolyzed water had no benefit for enhancing broiler performance during the starter, grower or finisher phases. Experiment two: Both nutrition and management exhibited an impact upon broiler lipid deposition. Feeding the mash diet reduced calorie deposition, while oil addition elevated energy in GI tract and carcass. Pelleting the mash diet elevated carcass energy while lowering GI tract energy. In the third study the Ketogenic diet assisted the broilerized birds return to a pullet with breeding potential while the every day and every other day feeding methods were interchangeable.

ADVISER'S APPROVAL: Dr. Robert Teeter